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USER'S MANUAL FOR NOZZLELESS ROCKET MOTOR INTERNAL BALLISTICS COMPUTER PROGRAM

David P. Harry, III, et al

Lockheed Propulsion Company

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LOCKHEED PROPULSION COMPANY

TECHNICAL REPORT AFRPL-TR-73-20

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13. ABSTRACT

The objective of this program was to develop a computer program capable of accurately predicting the internal ballistics of motors designed for operation without nozzles. To accomplish this, previously obtained data were examined in detail. In addition, 12 motors were fabricated and test fired to augment the range of available test data. The computer program developed had to consider the effects of erosive burning, grain deflection, and incomplete metal combustion upon nozzleless motor performance. Input requires knowledge of motor geometry, propellant thermochemistry, base burn rate, and specification of erosive burning and grain deflection parameters. Comparisons of predicted and actual results show that where an adequate data base exists, with regard to erosive burning and grain deflection effects, accurate predictions will be provided by the computer program. This applies to all performance parameters, including instantaneous thrust and pressure, burn time, and specific and total impulse. Even lacking such a data base, the program will correctly predict the overall parameters of specific impulse and total impulse. To fully utilize the capabilities provided by the computer program, further study of erosive burning and grain deflection is required. The technical program is described in AFRPL-TR-73-19.

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FOREWORD

This technical report summarizes work performed from 1 June 1972 to 31 January 1973 under Contract No. F04611-72-C-0076 by Lockheed Propulsion Company (LPC), Redlands, California, for the Air Force Rocket Propulsion Laboratory (AFRPL), Edwards, California.

The work reported herein was performed under the technical direction of Lt. H. Barbarika of the Air Force Rocket Propulsion Laboratory. The Lockheed Propulsion Company program manager was Mr. D. E. Taylor, and the project engineer was Mr. K. R. Small. Mr. D. P. Harry conducted computer program development efforts, and Mr. C. F. Price interpreted ballistic results and cinefluorographic test data. Propellant characterization and processing were under the direction of Mr. I. L. Markovitch and Mr. F. C. Anderson. The Lockheed Propulsion Company project number was (16) LPC-MPO 676.

This technical report has been reviewed and is approved.

Charles R. Cooke
Chief, Solid Rocket Division
AFRPL/MK

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SECTION I

INTRODUCTION AND SUMMARY

The potential of a solid rocket operating without an exit nozzle for low-cost or high-altitude applications has been known for some time. Recently, the feasibility of the concept was established in a test program conducted by United Technology Center (UTC) on Contract F04611-71-C-0050. Reproducibility of performance was demonstrated and grain shape variations that delivered increased performance were identified. The data acquired provided a good base for establishment of an analytical model to accurately predict the ballistic performance of nozzleless motors. Such a model would provide methodology to maximize the potential of such a rocket by design, and to permit evaluation of modifications that will optimize performance at no sacrifice in simplicity of fabrication.

The foundation for the computer program was a nozzleless rocket ballistics computer program already existing at LPC, which had evolved in sophistication over the year preceding this contract. The program had its inception in a conventional ballistics program with four descriptions of erosive burning included, and with allowances to treat axial variations with steady-state versions of the one-dimensional channel flow equations. Included in the original ballistics program was a projection of the grain profile shape. The program was modified to make it applicable to the fast transients that occur in ignition and tailoff. For the purpose of examining ignition and tailoff transients, the usual lumped volume approaches, which have been developed to apply to conventional rockets, are not applicable to the nozzleless rocket. This is because they are incapable of treating the important axial variations in the nozzleless rocket, which dominate its behavior. The program modification was developed from an examination of the pertinent, unsteady, one-dimensional flow equations. It was found that an approximate method of solution to the transient problem could be readily obtained. Briefly, it retains a time-dependent term in the continuity equation only while retaining all important axially dependent terms.

Computer program input requires detailed knowledge of motor geometry features and propellant thermochemistry. In addition, the user must select inputs related to erosive burning, grain deformation, and metal combustion. The output provides all overall performance parameters (head-end pressure, thrust, mass flow rate, etc), as well as a description of internal motor geometry, all versus time. Additional output is available as a user option. Serial runs only require input of changes. Computer run time varies between 10 seconds and 1 minute on a CDC 6400 machine.

This User's Manual completely describes and documents the nozzleless rocket motor internal ballistics computer program. Test cases are included to demonstrate the use of the program. The model is operational on the AFRPL computer facility.

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SECTION II

ANALYSIS

1. FLOW EQUATIONS

The equations for one-dimensional flow used in the computer program are based on the following assumptions:

- Particles occupy negligible volume compared to the gas
- Particle velocity is a constant fraction of gas velocity
- The gas follows perfect gas relationships
- Mass added from the propellant surface has no axial component of velocity

With these assumptions, the equations that apply are (symbols are defined in Appendix A):

STATE

$$p = \rho(1-\epsilon)Rg\ T$$

CONTINUITY

$$\frac{\partial}{\partial t}(\rho A) + \frac{\partial}{\partial x}\left[\rho\left|1-\epsilon(1-f)\right|U_g A\right] = \dot{m}_e$$

MOMENTUM

$$\rho A\left[1-\epsilon(1-f^2)\right]U_g\ \frac{\partial U_g}{\partial x} + \dot{m}_e\ U_g\left[1-(1-f)\ \epsilon_o\right] + A\ \frac{\partial p}{\partial x} + F_x = 0$$

ENERGY

$$Cp\ T + \frac{U_g^{\,2}}{2}\left[(1-\epsilon_o) + \epsilon_o f^2\right] = Cp\ T_F$$

Choking occurs when the gas phase velocity, U_g, becomes equal to the apparent sonic velocity, c, given by

$$c = \sqrt{\bar{\gamma}(1-\epsilon)\ Rg\ T}$$

$$\bar{\gamma} = \frac{\bar{c}_p}{\bar{c}_v}$$

where:

$\bar{c}_p$ = specific heat at constant pressure of the mixture (for $f \neq 1$)

$\bar{c}_v$ = specific heat at constant volume of the mixture (for $f \neq 1$)

The mass fraction of particles in the flow is higher when the particles lag behind the gas, and can be described in terms of the amount of lag and ϵ_o:

$$\epsilon = \frac{\epsilon_o}{f + (1-f)\,\epsilon_o}$$

2. EROSIVE BURNING CORRELATIONS

The computer program presently incorporates an erosive burn rate description of the form

$$r = r_o + a\,(G^m - G_o^{\,m})\left(\frac{Ug}{c}\right)^{0.5}$$

where:

m = 0.8

c = sonic velocity

a, G_o = constants determined by the propellant

To provide the user with some generality, the program also retains the Lenoir-Robillard form of erosive burn rate description

$$r = r_o + \frac{\alpha\,(G)^{0.8}}{(x)^{0.2}} \exp\left(-\frac{\beta\,\rho_s r}{G}\right)$$

where:

ρ_s = solid propellant density

α, β = constants determined by the propellant (α related theoretically to a heat balance)

3. ALUMINUM COMBUSTION AND SLIP FLOW

Empirical equations are used to fit results of individual particle calculations. The correlations used are:

$$\overline{F} = \left(\frac{L}{50}\right)^{0.6633} \left(\frac{p}{500}\right)^{0.1151} (1-0.0084\ D_o)$$

$$f_{Al} \equiv \frac{\overline{U}_{Al}}{V_f} = \frac{0.5534\left(\frac{L}{50}\right)^{0.1759}\left(\frac{p}{500}\right)^{0.2271}}{\left(\frac{D_o}{100}\right)^{0.0842}}$$

$$f_{Al_2O_3} \equiv \frac{\overline{U}_{Al_2O_3}}{V_f} = 0.9470\ \frac{\left(\frac{L}{50}\right)^{0.0234}}{\left(\frac{p}{500}\right)^{0.0381}}$$

where:

L = motor length, in.

p = head-end pressure, psia

D_o = initial diameter of aluminum agglomerate leaving propellant surface, microns

$\overline{F}$ = fraction of aluminum burned

$\overline{U}_{Al}$ = velocity of aluminum particle at motor exit, ft/sec

$\overline{U}_{Al_2O_3}$ = velocity of aluminum oxide particle at motor exit, ft/sec

V_f = gas velocity at motor exit, ft/sec

4. THERMOCHEMISTRY INTERPRETATION

Thermochemical properties of the combustion products determined from standard equilibrium thermochemistry programs are assumed input to the model (the input form is described in Section IV). The input should cover at least the range of the fraction of aluminum burned expected in the particular motor, and is obtained from so-called T* runs of the thermochemistry program, meaning that a fraction of the aluminum is treated as a "non-reacting specie". The theoretical thermochemistry program in use at AFRPL may be obtained from

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Edwards Air Force Base, CA 93523

Calculation of gas properties from thermochemical program inputs, the fraction of aluminum burned, and slip flow correlations employs the following relationships:

$$Rg = Ru/Mg$$

$$\epsilon_o = 1 - Mg\ (\text{Moles gas})/100$$

$$f = f_{Al_2O_3} + \frac{(1 - \bar{F})\ Al\ (f_{Al} - f_{Al_2O_3})}{\epsilon_o}$$

where Al is the fraction of aluminum in the propellant.

$$\gamma_p = Cp,p/(Cp,p - Rg\ \frac{\text{Moles gas}}{\text{Moles prod}})$$

$$\epsilon = \frac{\epsilon_o}{f\,(1 - \epsilon_o) + \epsilon_o}$$

$$Rp = (1 - \epsilon)\ Rg$$

$$\bar{\gamma}_\epsilon = \frac{Cp'}{Cp' - 1.987}$$

$$Cp' = Cp,g + (Cp,p\ \frac{\text{Moles prod}}{\text{Moles gas}} - Cp,g)/f$$

5. GRAIN DEFLECTION

Grain deflection is considered in the computer program as a product of steady-state deflection modified by the ratio of transient to steady-state motion. The steady-state deflection is obtained as a function of motor length from computer solutions to the boundary value problem for the specific propellant geometry of interest. The results are linear with head pressure to ambient pressure difference for a given pressure distribution in the port. Grain deflection has been found to be nearly linear with the web fraction burned for a given ΔP, and this approximation is used in the model:

$$\Delta r = \frac{x(t)}{x_{ss}} \cdot \frac{P_{head}}{P_{ref}} \left(1 - \frac{web}{web,i}\right) \left(\Delta r_{ss}\,(x)\right)$$

where the steady-state deflection for the initial web and a given reference pressure is input as a function of length. The throat web fraction is used as representative of the important effects on motor operation.

The ra..o of transient to steady-state deflection is determined by assuming the grain to act as a critically damped spring-mass system driven by a pressure ramp:

$$\ddot{x} + 2\omega_n \dot{x} + \omega_n^2 x = \dot{P}t/m + P_0/m$$

where

$$\omega_n^2 = \frac{K}{m}$$

The integrated equation for an increment of calculation where initial conditions are not zero is

$$\frac{x(t)}{x_{ss}} = \frac{1}{P_{head}} \left[e^{-\omega_n t} \left\{ K(1 - \omega_n t) x_0 + (2\omega_n x_0 + \dot{x}_0) Kt - P_0 (1 + \omega_n t) + \dot{P}(2/\omega_n + t) \right\} + P_0 + \dot{P}(t - 2/\omega_n) \right]$$

and the initial rate $\dot{x}$ is determined by differentiating x(t). The deflection equation is integrated with respect to time in the model in closed form for an increment $t = \Delta t$ but is iterated as $\dot{P}$ is iterated. Values of the input coefficients K and ω_n are selected to fit experimental data.

6. CHOKING CONSTRAINTS

Iterative calculation to satisfy choking constraints is by far the most time-consuming operation within the nozzleless motor ballistic prediction program. Consequently, sophisticated correction terms are generated to predict successive trial values. The logic used for the special cases that apply to nozzleless motors is summarized in the following paragraphs.

a. Choked Flow, Throat at Port Exit

A head-end pressure P(1) is selected and the integration down the port is performed. If the velocity of the throat is less than the local sonic velocity, an adjustment is made to decrease head-end pressure, and the iteration continues. If, on the other hand, the velocity exceeds the sonic velocity, a trap is executed that limits velocity and generates an error signal by "breaking" the momentum equation. An adjustment term is computed to increase P(1), and iteration continues until the specified convergence is obtained.

b. Subsonic Flow

If the entire motor is operating with subsonic flow, the head-end pressure is adjusted to cause exit static pressure to match ambient pressure, and again, an approximate relationship is used to calculate successive trial values.

c. Choked Flow, Throat in Port

Where the motor contains an exit cone, the throat is located initially near the nominal minimum area. Solution for the subsonic flow portion of the motor up to the throat is the same as previously described. The iteration is completed to match the throat constraint and then the supersonic portion is calculated using the same equations but with modified convergence logic because the computational stability is altered. Two added sets of logic are checked:

(i) If the flow expands supersonically to the exit, the problem is complete. The possibility that exit static pressure is sufficiently lower than ambient pressure to allow a fully expanded nozzle without separation is ignored in the model. The throat regression is faster than that in the exit cone and the expansion ratio decreases, causing (ii), below, but not an overexpanded nozzle.

(ii) If the flow is calculated to decelerate below the sonic velocity, the velocity is again constrained and an error signal is generated. Note that the mass addition in the port causes a second "throat" of significantly larger area than the first, and the minimum area may operate in subsonic flow. A sequential recovery procedure is required. The "throat" is first identified with the exit of the port. The integration of subsonic flow down the port is repeated and the new throat constraint location is identified by the criteria:

$$\frac{d\,A_p}{A_p} > \frac{w_{added}}{w}\,\frac{\gamma + 1}{1 + \epsilon_o} + \frac{2\,\bar{\tau}}{\bar{p}}$$

where the barred quantities are the average for the increment. Thus, the "throat" is located in the expansion region at the node where the area increase just overrides the effects of mass addition and friction. A note in program output is printed at each attempt to relocate the throat. The tentative solution is then iterated to the specified convergence accuracy.

SECTION III

PROGRAM STRUCTURE

The nozzleless rocket motor ballistics model is designed to compute a time-history of motor behavior during the simulated run. The logic of solving the equations presented in Section II is described in this section followed by a discussion of the computer program subroutine structure. The details of program input and output are given in Sections IV and V.

1. SOLUTION LOGIC

The general scheme employed in solving the equations of one-dimensional flow is shown in simplified terms in Figure III-1. The procedure that follows the initialization of a new case is as follows:

- A head-end pressure is assumed. The calculations for a single axial increment are made and iterated to completion. The successive increments down the port are then calculated until the choke point or exit is reached.

- At the choke point, the local Mach number is checked. If the calculated value is not within tolerance, a correction to head-end pressure is made and the calculation is restarted at the head. As successive iterations are made to satisy the choke constraint (outer loop), the axial stations (inner loop) are continuously iterated. The same logic applies if the throat is unchoked except that $p_{exit} = p_{amb}$ is the constraint.

- If a supersonic exit cone exists downstream of the throat, the axial increments are continued to the end of the motor.

- Parameters used in transient terms and integrating calculations are saved, and the time increment is advanced. The calculations resume with a new head-end pressure assumption.

- As the calculations reach the end of a specified run time, or the motor has burned out, the input for the next case is read and the new case is started.

The computational logic, thus, is arranged as a triple-loop structure with the axial increment (inner loop), choke constraint (outer loop), and time increments (stepping).

A more detailed diagram of program logic is shown in Figure III-2. This representation is still simplified with regard to the individual branching for special cases, but is intended to describe the function of groupings of

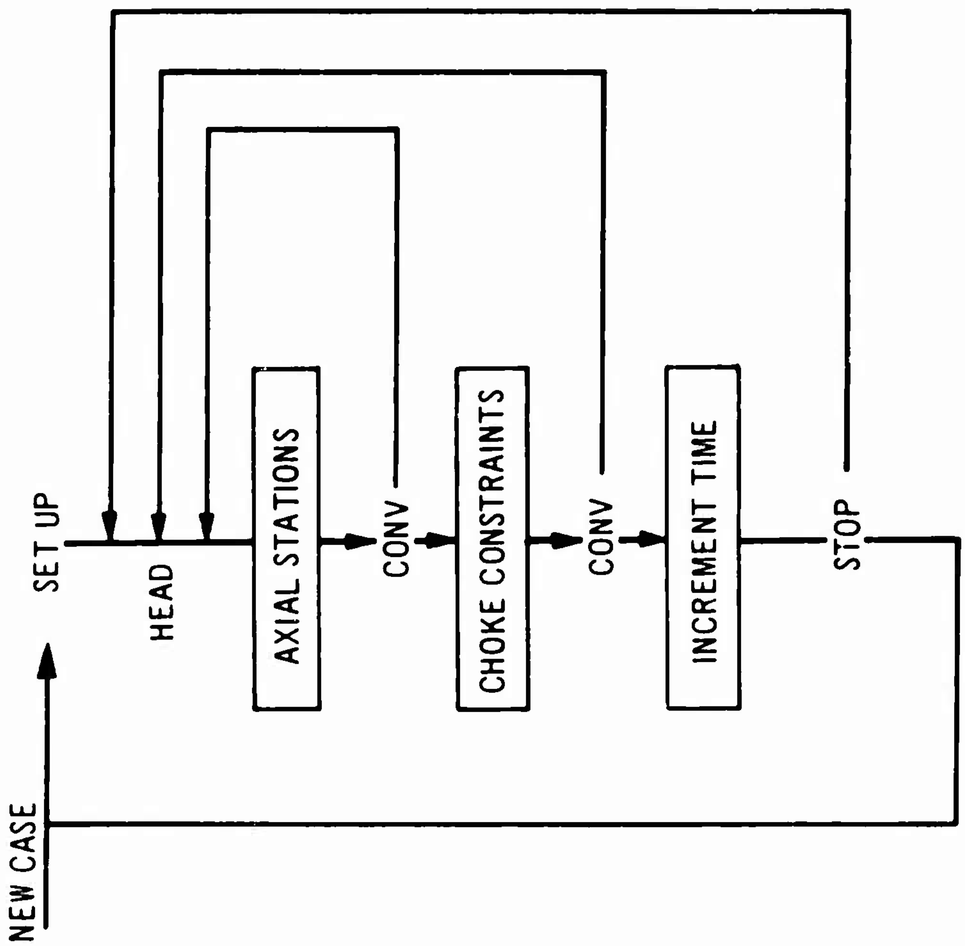


Figure III-1 Simplified Logic

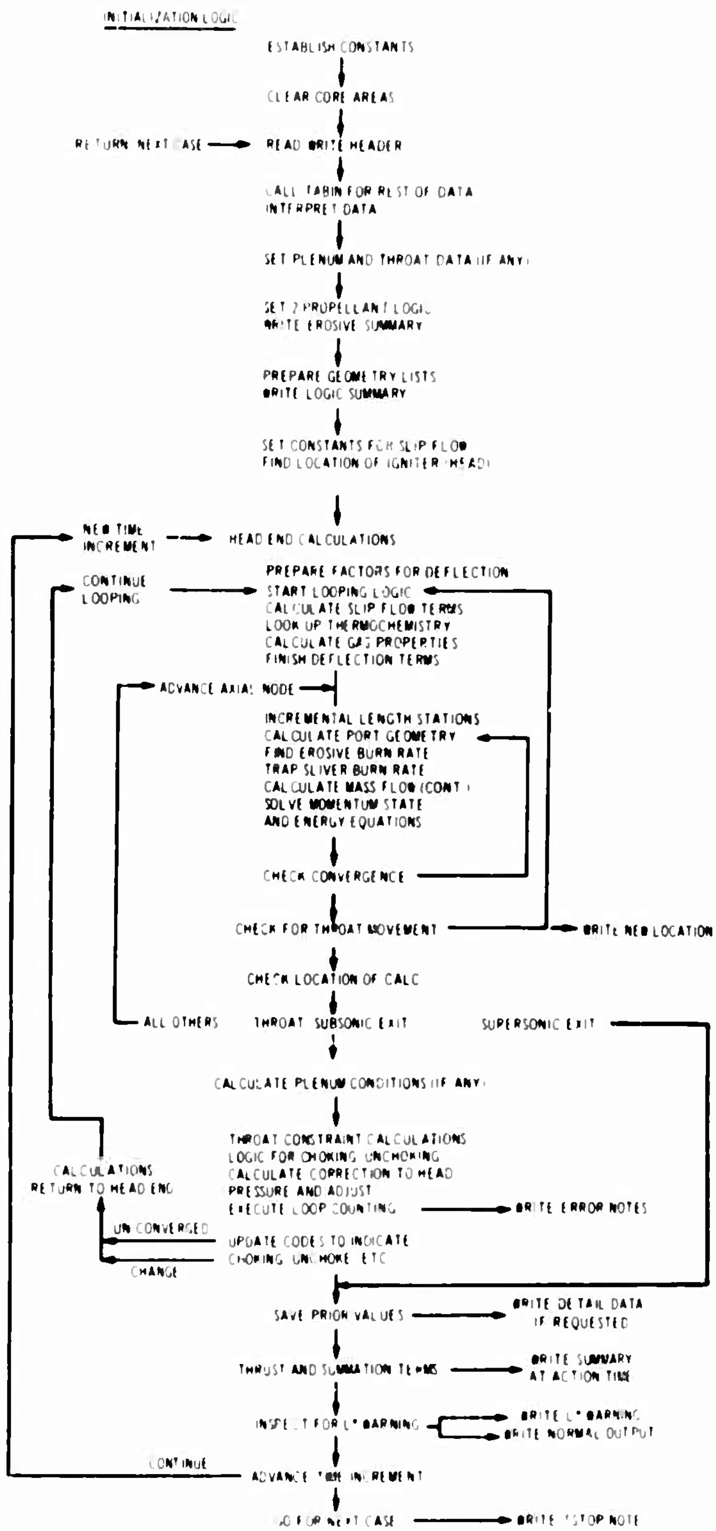


Figure III-2 Functional Representation of Program Logic

program steps internal to the program, and presumes valid input. Figure III-2 is organized in the same order as the source program.

- The compiled-in constants are established and some core areas are cleared to zero. The program does not require a clear core.

- A heading card is read and printed. An integer is required in CC1 to indicate another case; otherwise, a normal exit is interpreted.

- A subroutine to control the reading and organizing of tabular data is called by the main program. The remaining data, integers and real data input, are returned in intermediate storage which is inspected for non-zero (nz) values. Any nz values are then placed in working storage and overwrite the previous values.

- Logical interpretations are made of the input data; for example, the throat is assumed at the exit unless an input node number is given.

- Plenum and throat geometry for a nozzled motor is calculated. These steps are degenerate unless input data is provided.

- Interpretation of one or two propellant cases is made and some constants are computed. A printed note identifies the propellant and erosive burn model to be used.

- The geometry of the grain is established from tabular input of inner diameter, outer diameter, and axial step size. Also, some parameters are cleared or initialized to input values.

- A summary of the key words/data that describe program options is printed. For example, the input of aluminum particle size is used to key the fraction burned calculation, so that a zero value indicates that this option will not be used.

- Terms factored from the fraction burned and slip flow equations are calculated. Factors are removed from the calculation loops to reduce execution time.

- The location of the initial head end of the motor is established. The head is normally the physical head end, but is changed for special cases involving igniter location and fuse configurations.

- The following groups of calculations are repeated at each time increment of the problem. The igniter flow, if any, is determined from tabular input, an outer-loop convergence factor is calculated, and terms factored from the transient deflection equations are prepared. A series of parameters are set to initial values.

- The particle lag terms are completed. Since these values are assumed dependent on head pressure, they are constant down the port and are not recalculated at each axial station. Gas properties and deflection also use this interpretation, as follows.

- Input values of thermochemistry program data are interpolated from input tables as a function of the fraction of aluminum burned. The gas properties required to solve the equations of motion, such as the ratio of specific heats, the gas constants, and sonic velocity, are calculated.

- The transient deflection calculation is completed. The static shape terms from tabular input were placed in an array prior to the beginning of looping.

- The following calculations are made for each axial increment in the motor. Trial values for the initial time step are used from the previous axial station; all other trial values result from the previous iteration of the station. Special case logic for the head-end node, ignition options, or initial time, are not shown in the figure or discussed here. (However, they should be recognized in the program listing as I.EQ.L, IGN.GT.0, or TIME.EQ.0. branches.)

- The port geometry is calculated from the web burned, burning rate, and the input options of a circular port, two-dimensional port, or star fuse design. Symmetry is assumed in all cases.

- Base burn rate for the propellant at the axial station, as a function of local pressure, is found from an input table. The input table can be keyed to use log-log interpolation. The erosive contribution is then calculated.

- Trap logic is executed to determine the mass addition during tailoff of the motor. Some local conditions are calculated using the energy, state, and continuity equations.

- The deflected port area is determined, traps are executed to prevent crossing Mach 1, and the momentum equation is used to solve for pressure. The set of equations at each axial station is iterated with logic for low-speed flow, high-speed but subsonic flow, and supersonic flow.

- Looping logic allows 10 (or a larger input number) iterations and then accepts the result whether converged or not. The error is saved for printout should the outer loop converge when the inner loops are still in error.

- The geometry-flow relations used to determine the aerodynamic throat are checked, and logic to relocate the throat node is executed if necessary. Any changes are printed.

- The node number of the axial increment is checked to branch to the next step, as indicated in the figure. Throat and subsonic exits must branch to check exit constraints, and a supersonic exit bypasses to the output section. All other locations go back to calculate the next axial station.

- If a plenum and nozzle are modeled, the plenum pressure is calculated.

- An updated head pressure is calculated from the error in Mach number or a term created to indicate an overchoked prior calculation. If the exit pressure is less than ambient, the motor is unchoked and head pressure is iterated to force $p_{exit} = p_{ambient}$. A note is printed as the unchoke occurs. (If exit flow is supersonic, the exit pressure may fall below ambient. It is assumed that separation in the nozzle does not occur.)

- If the throat or exit constraint is not satisfied, loops are counted to 10 (or a larger input number). From 10 to 20 loops, the error is printed; and after 20 loops, the result is accepted if the error in head pressure is less than 5 percent (normal runs would converge exit conditions to 0.5 percent in Mach number). Otherwise, the run is terminated. The printed error messages indicate whether the calculations are oscillating or are overdamped and allow the user to determine whether the run is acceptable.

- A check is made on unchoked motors to determine if choking has occured, in which case the throat is located and motor conditions are reiterated with "choked" logic.

- Parameters along the motor are printed, if requested.

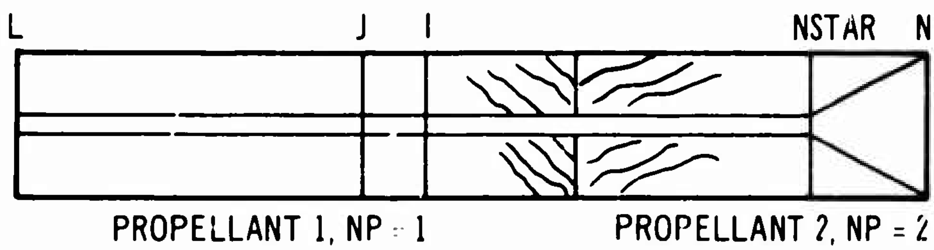
- Values used in transient terms or integrations are stored for use in the next time step.

- The instantaneous divergence angle from the throat to the exit, as well as thrust, are calculated. Summary terms are stored/accumulated until thrust decays to 10 percent of maximum, defining the action time of the motor: summary parameters are printed.

- The L* instability warning criteria is checked until a warning is printed or the head web burns out. The message appears ahead of the normal output for the time increment.

- Normal output parameters are printed, and input for a trajectory program is printed/punched if requested.
- If the run is the baseline for parametric studies, selected parameters are retained. After the baseline run, the stored values are used to calculate sensitivity coefficients. The parameters selected are those observable in experimental firings, namely, head pressure, thrust, exit burn rate, and burn rate at an input x-ray location.
- A series of terms are saved for continuing calculations, the time increment for the next step is determined, and the head pressure is guessed. Unless the run is completed, the calculations proceed to the next time increment at the head of the motor.
- Results of parametric studies are sequenced and output is printed if this option is used.

The indexing scheme employed in the program is shown in Table III-1 as an aid in following the details of the logic of special cases. For



example, if I is greater than NSTAR, the supersonic flow conditions in the exit cone are being calculated.

TABLE III-1

INDEX SCHEME

Symbol	Description
L	Head-end node, L = 1 except for ignition transient option
I	Axial node location of calculation
J	Prior axial node, usually J = I - 1, J > 0
NSTAR	Throat node
N	Exit node
NP	Propellant number, 1 or 2
NPAR	Location of the parameter being varied in parametric studies

2. SUBROUTINE STRUCTURE

The nozzleless ballistics model is essentially a single main program with three utility-type subroutines, as illustrated in Figure III-3. The subroutines have the following functions:

- DATA IN is a random read routine that interprets input of selected variables. DATA IN operates under the control of TABIN, which requests the reading of cards with integers or real data.

- TABIN is a routine which prepares input of tabular data. The addressing for the tables is arranged, indexes are initialized, and limits to table size established. Input of integers and non-tabular program inputs are simply passed back to the main program for interpretation.

- TAB is a routine to interpolate (or look up) values from the tabular inputs. Linear interpolation or log-log interpolation is used and no extrapolation is made; rather, the value at the boundary of the table is returned. The tables are assumed of the form

  $$z = f(x, y)$$

  with a call statement of the form

  CALL TAB (X, Y, Z, No)

  where No is a table number assigned in the MAIN program. The size, shape, type of interpolation, and order of table loading are established by input of the tables and thus are not transmitted to the main program.

  Internally, the logic is established to search the table by stepping from the prior point to the new one, consistent with an iterative program with highly repetitious call statements, in contrast to computing indexes.

  Tabular input may be degenerate in x, y, or both, and missing tables are interpreted as z = 0 with one and only one error message printed as a warning.

  All other functions and subroutines used by the program are believed to be standard library routines.

The groups of program output are shown in Figure III-3 to illustrate the relative position in the program where output is printed. A more explicit example is given in Section V.

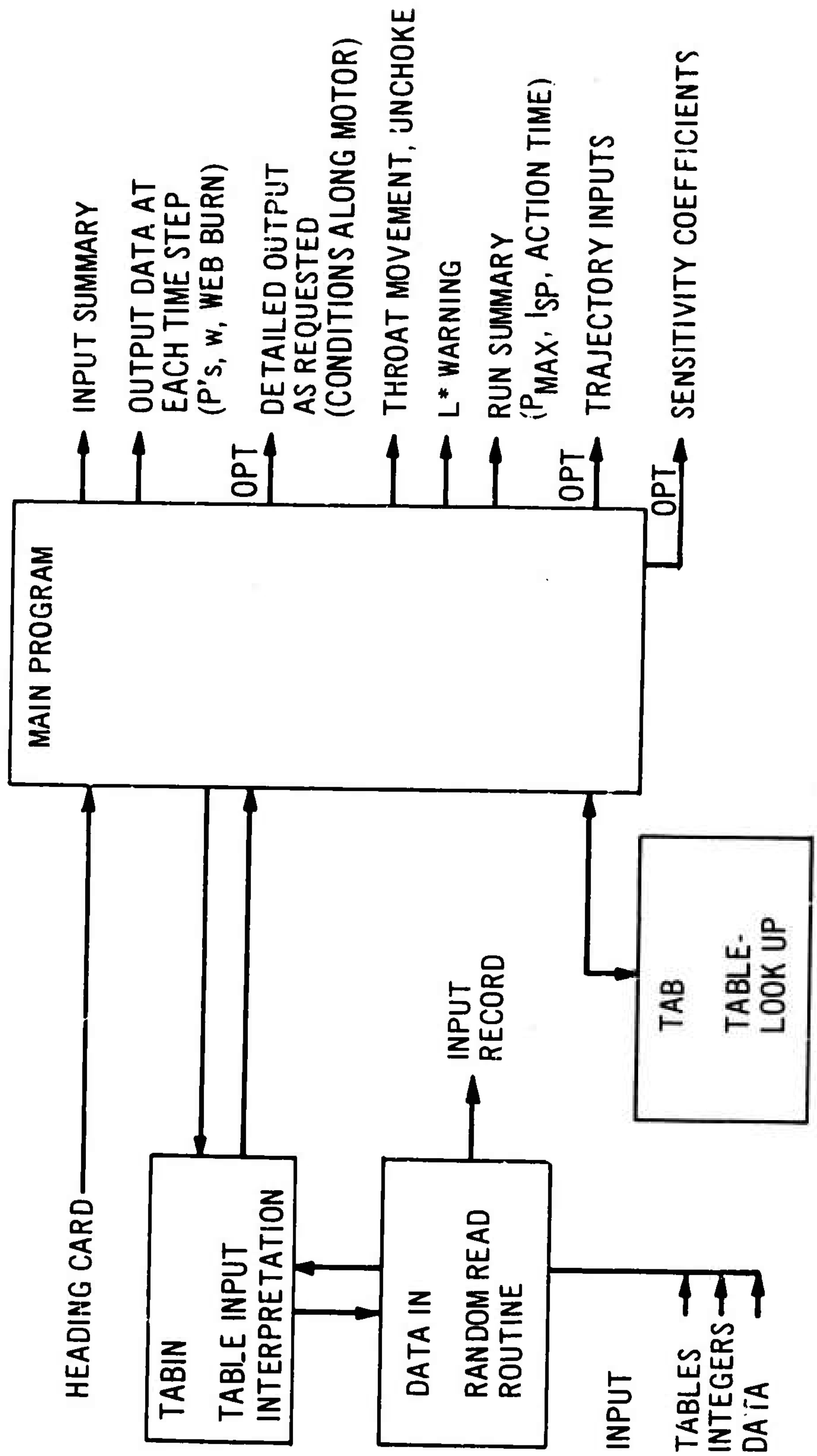


Figure III-3 Model Structure

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SECTION IV

INPUT REQUIREMENTS

The general requirement for input information needed to run the program is discussed first to show the type of data that must be available. Second, the scheme used to interpret the input is described, and finally, the specific word-by-word requirements are given. The rationale, in contrast to rules, is considered in Section V.

1. INFORMATION REQUIREMENTS

Motor geometry description must include the initial port diameter and grain outer diameter given as a function of motor length. An exit cone, if any, is part of the port diameter profile.

Propellant thermochemistry calculation outputs for the desired range of aluminum fraction burned, $\overline{F}$, from so-called T* runs, are expected. The input is given as parameters from the I_{sp} printouts in the units of standard equilibrium thermochemistry programs (Section II-4). The range of $\overline{F}$ should not be less than will be used in the run because extrapolation is not allowed: The limiting values of the given data will be used, and no warning is provided.

The igniter mass flow as a function of time and the upstream spreading rate are needed if an option using these parameters is requested.

Grain deflection is calculated from a shape function from stress-analysis program calculations and coefficients for the transient equation; both are required if deflection is to be included in the model. The importance of deflection to the simulation results varies with motor design and propellant mechanical properties, so a decision to neglect deflection must be made in each case. If case deflection is significant relative to a rigid case, this effect should be included in stress-analysis calculations.

Erosive burning coefficients for the propellant and base burn rate from strand tests are required. Again, the input must cover the range of pressures encountered in the run, usually from peak pressure down to abient or even below ambient if supersonic exit cones are simulated. If needed, the data must be extrapolated by the user.

Miscellaneous constants and selection or logic to control the program are needed to complete a problem definition, and are discussed in subsection IV-3.

2. INPUT SCHEME

A technique allowing maximum flexibility of problem input has been adopted. This scheme, however, should be understood because it is important in running multiple cases in a single computer access.

The first card in a case definition is a header card for identification of the problem, Figure IV-1. The header (1) is read from the main program and is immediately printed on the output. A 1 is required in the first column (c c 1); absence of the 1 results in a normal termination of the run.

The remaining input is controlled from the subroutine TABIN, but is actually read in DATA IN, in the sequence indicated in Figure IV-1. All of the data tables (2) are read first, with a limit of 50 tables and 3000_{10} words of storage, both about three times more than normal input for one case. The tabular input is assumed to continue until a completion code (loc 4 = -1) is given. The input in the remaining two sets (3) and (4) is then interpreted in the main program. Integer words (3) are logic controls for the calculation. and data words (4) include coefficients, constants, and some problem logic control words, to be described in detail in subsection 4.3.

The input is transferred to working storage in the main program (5) if non-zero (nz) values are given. As a result, only changes in the problem are needed in successive cases. Also, only input pertinent to the case and options to be used is required, so unneeded input can be completely ignored.

Since zero input is ignored, no "filling" is required, but values in the cards do no harm if desired for column alignment, etc. One limitation in the method is that options can not be "turned off" by inputting a zero in a later case.

In batch runs, any constants or tables may be replaced by new input, except with zero integers or constants as discussed. The tabular inputs are added into the lists and storage area, and the internal logic is readdressed to the new input. This approach has two implications:

(i) The new table is independent of the old in size, type, and interpolation method.

(ii) New tables add to the total number of tables (50 limit) and storage (3000 words), so the cumulative number in batch runs can exceed these limits.

3. DETAILS OF INPUT

In this subsection, the mechanics of card format and table input are considered, then the parameters and requirements are specified.

a. Format

Three card input formats are used by the program,

I1, 71H	Header, one card
4 (I2, I4, 6X), I2, 28A	Logic
6 (I2, F10), I2	Data

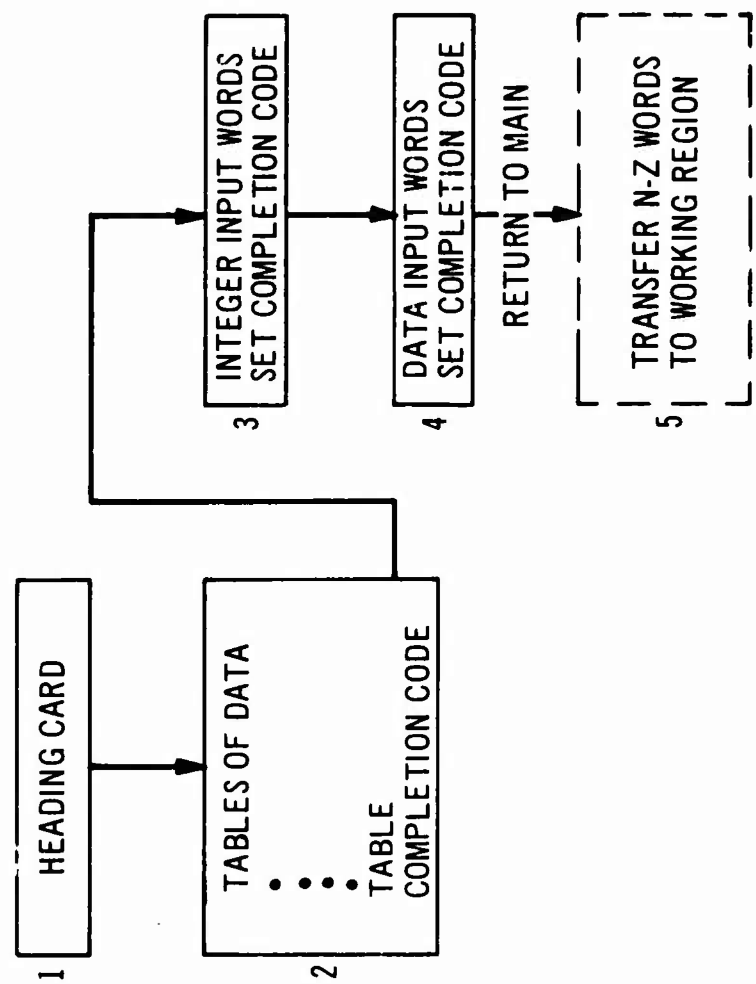

Figure IV-1 Input Groupings

For either logic (integer) words or data cards, the input is interpreted as (loc for location)

1-2	3-12	13-14	----
loc,	input, value	loc	----
I2,	I4, 6X or F10,	I2	----

The input cards are read in sets, and a set is assumed to continue until a completion sign is encountered. Two completion signs are recognized:

(i) A blank card

(ii) A negative location, i.e., location = -1 in any of the I2 fields on the card.

Note that the completion sign for tabular input is different in meaning and form (b4bb -1 in I2, I4).

Rules governing the interpretation of a card set include:

- Any number of cards may form a set.
- Any order of locations is acceptable.
- Zero values of input are ignored.
- If locations are repeated, the last value of input is used (overwrites).
- If a location is blank but data is given, a sequenced list is assumed, so the following two cards are equivalent:

1	10.	2	11.	3	12.	-1
1	10.		11.		12.	-1

The sequencing does not follow from card to card, so the first location on the next card must be given.

b. Tabular data

Data tables are assumed of the form $z = f(x, y)$. Tables are termed rectangular if the number of x arguments in the rows is the same for each of the columns of y arguments. A nonrectangular table, then, has a varying number of x arguments in the columns.

The card sets to input a table are given in Table IV-1 with the location of the words in the sets. The logic (integer) card set is always required and must include a table number and a completion sign. The number of y columns (NY) in location 5 and x rows (NX) in location 6 must be given if more than one. Location 3 is used to key log-log interpolation if desired, and a (+) value in location 4 keys a nonrectangular table.

Usually, one set of y values, one set of x values, and NY sets of z values compose a table. If only one y column is specified, the set of y values is omitted. If a nonrectangular table is specified, the number of x values in each column must be given, starting in location 7, and an x-argument set is required for each y argument.

c. Assignment of Input Tables

The numbers of input data tables are assigned in the main program due to compiled-in constants in the call statement:

CALL TAB (X, Y, Z, NO)

The correspondence of input data and the table numbers, NO, is given in Table IV-2 with the engineering symbol, FORTRAN symbol, and assumed arguments of the tables. In Table IV-2, data that is designated as "optional" is needed only if the related option is specified. Data that is designated as required is almost always needed since zero values of the parameter (Z) are rarely meaningful; the possible exception is the list of times of detailed output where no input results in printout of all time steps.

Symbols in Table IV-2 are separately defined in Appendix A.

d. Integer Inputs

Up to 12 integer words may be input to control program options, as shown in Table IV-3. Only two are always required, the number of nodes (increments +1) and the erosion model number (plus loc (4) = NUM (4) = -1 to indicate the end of data tables).

e. Data Input Words

Up to 40 data (real) words may be input to complete the input constants and control options in the program, as listed in Table IV-4. Note that one data set is used, regardless of the number of cards, as discussed in subsections IV-2 and IV-3.

In Table IV-4, data required for most runs is indicated. Data related to optional calculations are required if the option is requested. For example, if X2 is given in Z(6) to "key" use of two propellants, then Z(31), Z(33), Z(35), Z(37) are needed to define the second propellant and an erosive burning correlation. In addition, the base burn rate should be input in table 1 and the correlation type in NUM (3).

TABLE IV-1

INPUT OF TABULAR DATA

Input for Form Z = f (X, Y)

Input Type	Input	Description
Integer card set	Required	Control constants
Data card set	Required if NY >1 Omit if NY = 1	Y values
Data card sets	1 set if rectangular NY sets if nonrectangular	X values
Data card sets	NY sets required	Z values

Integer Cards 4 (I2, I4, 6x), I2, 28A

Location	Input	Description
1	Required	Table number (see Table IV-2)
3	Optional	Key to LOG-LOG interpolation (+)
4	Optional	Table type, nonrectangular = (+) (Note that (-) is key to end table inputs)
5	Optional	Number of Y (columns) values, required if NY >1
6	Optional	Number of X (rows) values, required if NX >1
7 to 25	Optional	Number of X values in 2nd----19th Y columns, nonrectangular tables

Data Card Sets 6 (I2, F10), I2

Location	Input	Description
1	Optional	List of X, Y, or Z values sequenced from Location 1
Any	Required	Completion sign

NOTES:

1. A table can degenerate to one point in X, Y, or both.
2. Interpolation is linear with no extrapolation: values at boundary of table are returned.
3. A missing table causes Z = 0 and one (only one) error message.

TABLE IV-2

INPUT TABLE ASSIGNMENTS

No.	Function	Input	Symbol	Form z (x, y) z	x	y
1	Propellant burn rate	Required	r_o	R0	p	PNUM
2	Igniter mass flow	Optional	w_{ign}	W (L)	t	-----
3	Motor geometry	Required	d_i d_o	D DMAX	x	$1 = d_i$ $2 = d_o$
4	Axial increment length	Required	$\frac{dx}{dx,_{nom}}$	DX	x/L	---
5	Time increments	Required	dt	DELT	6	---
6	Time of detail output	Required	---	TLIST	Counter	---
7	Nominal deflection	Optional	---	DEFL0	x	---
8	Chamber temperature	Required	T_c	TC	$\overline{F}$	---
9	Specific heat of products	Required	$c_{p, p}$	CPP	$\overline{F}$	---
10	Specific heat of gas	Required	$c_{p, g}$	CPG	$\overline{F}$	---
13	Moles of gas	Required	---	MOLG	$\overline{F}$	---
14	Moles of products	Required	---	MOLP	$\overline{F}$	
15	Molecular wt of gas	Required	Mg	MWTG	F	---
11	Time of sensitivity calc	Optional	---	TPART	Counter	---
12	List of parameters (parametric sensitivity)	Optional	---	NPAR	Counter	---
16	Fraction of head burning	Optional	---	HEADW	t	---

TABLE IV-3

INTEGER INPUTS

Location	Symbol	Input	Description
NUM (1)	N	Required	Number of nodes (increments +1); use 10, 19, or 28 (limited by output format)
NUM (2)	KODE	Required	Erosion model number, first or only propellant
NUM (3)	KODE	Optional	Second erosion model number
NUM (4)	-----	Required = -1	Keys this list
NUM (5)	KEY	Optional	Code word requesting calculation of parametric variations
NUM (6)	IGN	Optional	Key (+) for ignition at Δt option
NUM (7)	NSTAR	Optional	Throat node number, a slight aid to program execution speed
NUM (8)	NXRAY	Optional	Node number of local $\dot{r}$ output for parametric studies. Not used without KEY
NUM (9)	L	Optional	Node number for ignition if <u>not</u> at head of motor
NUM (10)	LOOPM	Optional	Number of loops run without error message (10 assumed if not greater)
NUM (12)	LIST	Optional	Key (+) to output for trajectory program inputs

TABLE IV-4

DATA INPUT WORDS

Location	Symbol		Units	Input	Description
Z (1)	-	TSTOP	sec	Required	Computation time if desired less than burn-out time
Z (2)		TRISE	sec	Optional	Approximate time of fast pressure rise
Z (3)	-	ALUM	---	Required	Aluminum fraction in propellant, required if not zero
Z (4)	β	BETA	---	Required	Coefficient, shear stress calculation
Z (5)	μ	MU	lb/in. -sec	Required	Viscosity of combustion products
Z (6)	-	X2	in.	Optional	Length at beginning of second propellant
Z (7)	L	XE	in.	Required	Motor length
Z (8)		XPLEN	in.	Optional	Plenum length
Z (9)		DPLEN	in.	Optional	Plenum diameter
Z (10)		DTH	in.	Optional	Throat diameter
Z (11)		PPLEN	psi	Optional	Initial plenum pressure (if nz, Z(8) - Z(10) are then REQ'D)
Z (12)		WIDE	in.	Optional	Width of star sheet, key to star geometry calculations
Z (13)		HIGH	in.	Optional	Motor width, key to two-dimensional geometry calculations
Z (14)		STAR	-	Optional	Number of points in star design
Z (15)		VFZ	in./sec	Optional	Velocity of upstream ignition propagation

TABLE IV-4 (Continued)

Location	Symbol	Units	Input	Description
Z (16)	WFZ	lb/sec	Optional	Mass flow due to fuse combustion (Z(15) is then REQ'D)
Z (17)	EPSP	-	Optional	Term to determine port-to-plenum pressure rise in nozzled motor
Z (18)	STEP	-	Optional	Code word, restart parametric variations
Z (19)	DOME	-	Optional	If negative, key to hemispherical head geometry
Z (20)	CONV	-	Optional	Convergence ratio, suggest 0.0005 (0.05% local, 0.1% mid, 0.5% throat accuracy)
Z (21)	CHOKE	-	Optional	Initial conditions assumed choked if positive
Z (22)	PSTART	psia	Required	Initial head pressure guess
Z (23)	RHOAMB	$lb/in.^3$	Optional	Initial gas density in port
Z (24)	PAMB	psia	Optional	Ambient pressure
Z (25)	FACTOR	-	Required	Loop gain factor, suggest 1.1
Z (26)	KD	$lb/in.^3$	Optional	Spring constant in transient deflection calculation (10k - 50k)
Z (27)	WN	rad/sec	Optional	Undamped natural frequency in transient deflection and key to calculation (40 - 100)

TABLE IV-4 (Continued)

Location	Symbol	Units	Input	Description
Z (28)	PREF	psia	Optional	Reference pressure used in nominal grain deflection input (Table A-2)
Z (29)	ALPHAN	-	Required	Relative value of L* correlation to 70^0F value
Z (30)	GO2 or BH	-	Required	First coefficient in erosive burning model, first propellant
Z (31)	GO2 or BH	-	Optional	First coefficient in erosive burning model, second propellant
Z (32), Z (33)	XKG or PR	-	Required, Optional	Second coefficient, as Z(30) - Z(31)
Z (34), Z (35)	XM	-	Required, Optional	Exponent, as Z(30) - Z(31)
Z (36), Z (37)	RHO	$lb/in.^3$	Required, Optional	Propellant density
Z (38)	DALUM	microns	Optional	Aluminum mean particle diameter, key to fraction burned calculations
Z (39)	SALOX	-	Optional	Slip ratio; Al_2O_3
Z (40)	SALUM	-	Optional	Slip ratio, aluminum

Similar groupings apply for fraction burned calculations Z(38) - Z(40) and for a motor with a nozzle Z(8) - Z(11), Z(17).

A special comment regarding the loop gain FACTOR in location Z(25) is required. The Mach number convergence criteria at the throat has a tendency to change for different problem definitions, so the solution can diverge or become overdamped and require excessive iteration. Output is provided to indicate the type of difficulty so that adjustment can be made in later runs: decreasing the input FACTOR damps the calculation.

Parametric studies are performed by perturbing individual parameters and repeating the case under program control. From differences between results at specified times, a sensitivity parameter is calculated and output; the output is necessarily a finite difference table (in contrast to slopes). Input requirements are:

(1) STEP = 1. to key logic

(2) TPART in table 11, list of times desired in sequence

(3) NPAR in table 12, list of locations, in the input array Z, of the desired parameters to be perturbed.

The number of output parameters and times are limited to 5 and 15, respectively, by dimensioning of array H(9, 15) and can be easily modified. The locations must be input as real variables to conform to the table input format.

SECTION V

SAMPLE CASES

The sample cases given in this section are intended to illustrate model operation; thus they are not specific motor designs.

The output listing of a sample case is shown in Table V-1 and serves as an input example as well, since all input is output on the listing. The format is expanded in printing but the output represents the appearance of the input cards. The words LOGIC and DATA are added at the left to show if integer or real data was expected by the random-read subroutine (for diagnosis of input errors). Comments after LOGIC are input on the cards and are not used by the program.

As an example of the input of tabular data, the third table from the top is input as loc = 1, integer = 3 to identify the motor geometry table. Location 5 specifies that 2 values of y are to be used, and location 6, because it follows 5 in sequence,[1] specifies 3 values of x. A completion code (-1) is in the fourth location field. The two values of y are sequenced from location 1 in the card, and the set is terminated by a completion code. The three x values form a set, and two sets of z finish the table. The data in this table establish a port diameter (y = 1) tapering from 0.621 inch at the head to 0.64 inch at a motor length of 39.24 inches, then flaring to 1.46 inches at a length of 40 inches. The grain diameter (y = 2) is 1.96 inches.

The last two groups of input are indicated by the 4 -1 in the third field at the end of the table input. This case used 19 nodes and burn rate model 1. The last six lines of DATA are the remaining input, as one set.

The comments on the next half-page of the listing summarize the problem setup before calculation begins. The first comment, indicating that no table 11 was input, is a warning, but the table is not required in this case. The next line summarizes the erosion model for propellant 1; since there is only one, a second line is not printed. A rough summary of geometry is printed but the throat is assumed at the exit since no node location was input (in NUM (7)). The list of options shows that igniter flow, fraction burned, and grain deflection are keyed.

The heading at the top of the next page indicates the axial node locations and is a good check on the related inputs. As calculations within the motor begin, the throat is recognized at 39.2 inches.

---

(1) The output shows "zero" rather than the assumed location. This choice is made to aid in diagnosing errors in input cards (the card "image" is returned).

(The reverse is blank)

TABLE V-1

SAMPLE CASE OUTPUT LISTING

```
  2X40   160    2/6/73

LOGIC
            1    6                6    4                -1
 DATA       1    0.000000        -0    1.000000         -0     2.000000      -0     3.000000      -1
 DATA       1     .100000        -0    1.000000         -0     2.000000      -0   160.000000      -1

LOGIC
            1    1                3    1                 5    1              -0    12             -1
 DATA       1   10.000000        -0  100.000000         -0   300.000000      -0   500.000000      -0 1000.000000     -0 1500.000000  -0
 DATA       7 2000.000000        -0 2500.000000         -0  3000.000000      -0  3500.000000      -0 4000.000000     -0 5000.000000  -1
 DATA       1     .051000        -0     .190000         -0     .322000      -0      .410000      -0     .560000     -0     .670000  -0
 DATA       7     .750000        -0     .800000         -0     .830000      -0      .875000      -0     .945000     -0    1.070000  -1

LOGIC
            1    3                5    2                -0    3              -1
 DATA       1    1.000000        -0    2.000000         -1
 DATA       1    0.000000        -0   19.240000         -0    40.000000      -1
 DATA       1     .621000        -0     .640000         -0     1.460000      -1
 DATA       1    1.960000        -0    1.960000         -0     1.960000      -1

LOGIC
            1    5                6    3                -1
 DATA       1    0.000000        -0     .100000         -0      .100000      -1
 DATA       1     .010000        -0     .050000         -0      .100000      -1

LOGIC
            1    2                6    2                -1
 DATA       1    0.000000        -0     .030000         -1
 DATA       1     .550000        -0

LOGIC
            1    4                5    6                -1
 DATA       1     .390000        -0     .400000         -0      .890000      -0      .900000      -0     .960000     -0     .961000  -1
 DATA       1    1.900000        -0     .900000         -0      .900000      -0      .555000      -0     .555000     -0     .344000  -1

LOGIC
            1    7                6    3                -1
 DATA       1   31.390000        -0   39.240000         -0    40.000000      -1
 DATA       1    0.000000        -0     .010000         -0

LOGIC          LBR  LPC
            1    8                6    5                -1
 DATA            0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1 2270.000000        -0 2650.000000         -0  2968.000000      -0  3214.000000      -0 3377.000000     -1

LOGIC
            1    9                6    5                -1
 DATA       1    0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1    9.782100        -0   10.417500         -0    10.965900      -0    11.426300      -0   11.790800     -1

LOGIC
            1   10                6    5                -1
 DATA       1    0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1   10.255700        -0   10.080400         -0     9.792100      -0     9.457700      -0    9.189100     -1

LOGIC
            1   13                6    5                -1
 DATA       1    0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1    3.424000        -0    3.434000         -0     3.460000      -0     3.505000      -0    3.567000     -1

LOGIC
            1   14                6    5                -1
 DATA       1    0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1    4.165000        -0    4.082000         -0     4.014000      -0     3.957000      -0    3.896000     -1

LOGIC
            1   15                6    5                -1
 DATA       1    0.000000        -0     .250000         -0      .500000      -0      .750000      -0    1.000000     -1
 DATA       1   23.360000        -0   22.010000         -0    20.620000      -0    19.350000      -0   18.620000     -1

LOGIC
            1   19               -0    1                 4   -1              -1
 DATA       1   10.000000         4   53.000000         -0      .000004       7    40.000000       3     .200000     -0
 DATA      20     .000500        -0    1.000000         -0  1100.000000      -0      .000100      -0   14.000000     -0     .800000  -0
 DATA      26 16000.000000       -0   40.000000         -0  1000.000000      -0     1.000000      -0
 DATA      38   20.000000        -0     .947000         -0      .554300      -0
 DATA      19    1.000000        29     .889000         -0
 DATA      30     .628000        32     .178400         36      .064000      -1

 REFERENCE TO UNCORRELATED TABLE NUMBER   11    0

ERUSION MODEL NO 1 FOR PROPELLANT 1          RHO =  .0640    K1 =  .6280    K2 =  .1784    EXP = 1.00    TO LENGTH =   0.0 IN.

 NOMINAL GEOMETRY
              HEAD     THROAT     EXIT

 LENGTH                 40.00     40.00
 INNER DIAM     .62      1.46      1.46
 OUTER DIAM    1.96      1.96      1.96

 DETAILED GRAIN DESIGN INPUT IN TABLE 3 TO USE 19 NODES SPACED AS INPUT IN TABLE 4


 CONTROL WORDS IN INPUT (NON-ZERO IS KEY)
          PARAMETRIC VARIATION KEY    0        XRAY NODE AC 15
          IGNITION INPUT DT OPTION    0
          2-DIMENSIONAL GRAIN KEY  0.000 (HIGH)
          N-POINT STAR GRAIN KEY   0.000 (WIDE)
          FUSE IGNITION CONTROL      0.0 (RATE)
          HEAD-END DOME DESIGN       1.0
          PLENUM-THROAT CALC, P =    0.0
          FRACTION BURNED KEY D =   20.0 MICRONS
          GRAIN DEFLECTION KEY AN   40.0
```

	PRESSURE			THRUST	FLOW	WEB BURNED / LENGTH										
TIME	HEAD	EXIT	PLEN			0.00	8.00	16.00	20.00	24.00	28.00	32.00	36.00	38.47	40.00	LOOP
P*	PT*	ISP	IMP	SUM W	DEFL											

THROAT LOCATION AT NODE 18 AT LENGTH 39.2 IN. SLOPE = 1.34

.01	1183.0	42.4	14.0	435.	2.090	.003	.003	.004	.004	.004	.004	.004	.005	.005	.001	5
553.5	774.5	208.1	2.	.010	.000											
10	-2.8814E-02	2.4416E+03	3.2579E-01	1.0000E+00												
11	-1.7436E-02	2.4416E+03	3.2579E-01	1.0000E+00												
.02	2441.3	79.4	14.0	1041.	4.652	.013	.014	.015	.016	.018	.019	.021	.023	.025	.006	12
1129.9	1979.5	214.6	13.	.159	.003											
.04	2633.3	135.8	14.0	1406.	6.545	.029	.030	.035	.038	.041	.046	.051	.057	.063	.017	1
1181.5	2380.3	214.8	36.	.171	.009											
.07	2225.7	149.9	14.0	1508.	7.096	.050	.053	.062	.067	.074	.082	.092	.103	.113	.037	5
957.0	1702.5	212.5	76.	.358	.016											

	TAU	G	V	P	A	W	R	RHO
1	0.	0.	0.	1.7312E+03	4.7616E-01	0.	7.0870E-01	4.6914E-04
2	0.	6.3882E-01	2.1082E+03	1.7260E+03	4.8009E-01	4.5506E-01	7.0835E-01	4.6790E-04
3	3.0487E-03	1.2673E+00	4.2165E+03	1.7110E+03	4.9235E-01	9.2585E-01	7.4291E-01	4.6412E-04
4	1.0669E-02	1.8952E+00	6.3961E+03	1.6849E+03	5.0908E-01	1.4316E+00	7.9262E-01	4.5755E-04
5	2.2854E-02	2.5233E+00	8.7033E+03	1.6458E+03	5.3008E-01	1.9847E+00	8.5425E-01	4.4769E-04
6	3.3065E-02	2.8366E+00	9.9248E+03	1.6207E+03	5.4225E-01	2.2323E+00	8.8903E-01	4.4134E-04
7	3.8293E-02	3.1493E+00	1.1208E+04	1.5912E+03	5.5561E-01	2.5964E+00	9.2636E-01	4.3388E-04
8	4.7568E-02	3.4608E+00	1.2569E+04	1.5568E+03	5.7027E-01	2.9284E+00	9.6620E-01	4.2517E-04
9	5.7957E-02	3.7705E+00	1.4729E+04	1.5168E+03	5.8633E-01	3.2803E+00	1.0085E+00	4.1501E-04
10	6.9603E-02	4.0779E+00	1.5619E+04	1.4701E+03	6.0384E-01	3.6537E+00	1.0528E+00	4.0316E-04
11	8.2652E-02	4.3813E+00	1.7376E+04	1.4155E+03	6.2307E-01	4.0505E+00	1.0989E+00	3.8945E-04
12	9.7430E-02	4.6776E+00	1.9367E+04	1.3510E+03	6.4447E-01	4.4731E+00	1.1476E+00	3.7301E-04
13	1.1314E-01	4.9435E+00	2.1576E+04	1.2760E+03	6.6720E-01	4.9230E+00	1.1950E+00	3.5382E-04
14	1.2940E-01	5.1483E+00	2.3953E+04	1.1906E+03	6.8970E-01	5.3995E+00	1.2356E+00	3.3178E-04
15	1.4722E-01	5.3345E+00	2.7046E+04	1.0839E+03	7.1499E-01	5.9039E+00	1.2779E+00	3.0460E-04
16	1.6178E-01	5.4340E+00	2.9674E+04	9.9879E+02	7.3298E-01	6.2295E+00	1.3058E+00	2.8266E-04
17	1.8235E-01	5.5095E+00	3.3770E+04	8.7810E+02	7.5478E-01	6.5685E+00	1.3369E+00	2.5170E-04
18	2.0722E-01	5.5071E+00	3.9351E+04	7.3708E+02	7.7586E-01	6.7870E+00	1.3606E+00	2.1610E-04
19	9.2592E-02	2.3946E+00	7.1557E+04	1.4247E+02	1.9640E+00	6.9802E+00	6.5294E-01	5.1653E-05

	PRESSURE			THRUST	FLOW	WEB BURNED / LENGTH										
TIME	HEAD	EXIT	PLEN			0.00	8.00	16.00	20.00	24.00	28.00	32.00	36.00	38.47	40.00	LOOP
P*	PT*	ISP	IMP	SUM W	DEFL											
.11	1731.2	142.5	14.0	1458.	6.980	.079	.083	.096	.105	.116	.128	.143	.158	.170	.063	0
737.1	1297.9	203.8	133.	.628	.018											
.21	1103.5	126.5	14.0	1321.	6.499	.143	.150	.172	.187	.204	.223	.244	.266	.283	.122	6
467.2	922.6	203.2	272.	1.302	.011											
.31	774.2	104.0	14.0	1139.	5.758	.198	.205	.233	.251	.271	.294	.319	.344	.362	.165	2
329.4	579.9	197.9	395.	1.915	.005											
.41	588.9	92.0	14.0	1008.	5.189	.245	.252	.283	.303	.326	.350	.377	.404	.423	.204	4
252.8	445.1	194.3	503.	2.462	.003											
.51	476.5	81.4	14.0	910.	4.772	.287	.294	.327	.348	.372	.398	.426	.453	.472	.235	4
205.7	362.1	190.7	599.	2.960	.002											
.61	407.4	89.2	14.0	854.	4.659	.325	.332	.365	.388	.413	.440	.468	.495	.513	.252	5
174.8	307.8	183.4	687.	3.432	.001											
.71	353.5	73.3	14.0	777.	4.178	.361	.367	.401	.424	.449	.477	.505	.533	.550	.252	5
153.4	270.0	186.1	768.	3.974	.001											
.81	312.4	75.9	14.0	734.	4.027	.395	.401	.433	.457	.483	.510	.539	.566	.583	.252	5
138.1	242.2	182.4	844.	4.284	.001											
.91	283.4	73.8	14.0	699.	3.916	.427	.433	.464	.487	.514	.541	.570	.597	.612	.252	6
125.6	221.1	178.6	916.	4.681	.000											

	TAU	G	V	P	A	W	R	RHO
1	0.	0.	0.	2.6111E+02	1.8536E+00	0.	3.0123E-01	7.4890E-05
2	0.	1.3831E-01	2.8126E+03	2.5971E+02	1.8576E+00	3.7225E-01	3.0046E-01	7.4517E-05
3	0.	2.7196E-01	5.6136E+03	2.5556E+02	1.8893E+00	7.4443E-01	2.9814E-01	7.3414E-05
4	0.	3.9466E-01	8.3480E+03	2.4890E+02	1.9547E+00	1.1177E+00	2.9438E-01	7.1640E-05
5	0.	5.0269E-01	1.0993E+04	2.4011E+02	2.0504E+00	1.4934E+00	2.8934E-01	6.9291E-05
6	0.	5.5070E-01	1.2285E+04	2.3503E+02	2.1085E+00	1.6823E+00	2.8659E-01	6.7930E-05
7	0.	5.9473E-01	1.3561E+04	2.2955E+02	2.1728E+00	1.8722E+00	2.8316E-01	6.6458E-05
8	0.	6.3521E-01	1.4838E+04	2.2365E+02	2.2428E+00	2.0641E+00	2.8045E-01	6.4972E-05
9	0.	6.7290E-01	1.6145E+04	2.1728E+02	2.3172E+00	2.2591E+00	2.8101E-01	6.3155E-05
10	0.	7.0844E-01	1.7518E+04	2.1033E+02	2.3946E+00	2.4576E+00	2.8126E-01	6.1280E-05
11	0.	7.4180E-01	1.8976E+04	2.0276E+02	2.4751E+00	2.6601E+00	2.8112E-01	5.9236E-05
12	0.	7.7292E-01	2.0551E+04	1.9445E+02	2.5590E+00	2.8657E+00	2.8047E-01	5.6991E-05
13	0.	8.0279E-01	2.2332E+04	1.8511E+02	2.6430E+00	3.0742E+00	2.7925E-01	5.4472E-05
14	0.	8.3287E-01	2.4496E+04	1.7416E+02	2.7219E+00	3.2850E+00	2.7732E-01	5.1520E-05
15	0.	8.6160E-01	2.7234E+04	1.6085E+02	2.8008E+00	3.4971E+00	2.7396E-01	4.7939E-05
16	0.	8.7877E-01	2.9479E+04	1.5054E+02	2.8486E+00	3.6279E+00	2.7061E-01	4.5173E-05
17	0.	8.9598E-01	3.2403E+04	1.3642E+02	2.8938E+00	3.7578E+00	2.6497E-01	4.1403E-05
18	0.	9.0957E-01	3.8178E+04	1.1658E+02	2.9398E+00	3.8365E+00	2.5493E-01	3.6141E-05
19	0.	8.7764E-01	4.7255E+04	8.6857E+01	3.0172E+00	3.8365E+00	2.2475E-01	2.8127E-05

```
              PRESSURE          THRUST   FLOW                                     WEB BURNED / LENGTH
TIME    HEAD    EXIT    PLEN                       0.00   8.00  16.00  20.00  24.00  28.00  32.00  36.00  38.47  40.00  LOOP
     P*      PT*     ISP     IMP     SUM W    DEFL

1.01   261.1   85.9   14.0    671.   3.837         .458   .463   .494   .516   .543   .570   .599   .625   .640   .252   6
   116.6   204.8   174.8    984.   5.069    .000

1.11   241.7   78.6   14.0    645.   3.757         .487   .492   .522   .544   .570   .598   .626   .652   .660   .252   6
   113.3   193.3   171.8   1050.   5.449    .000
19  2.6537E-03

1.21   214.6   90.3   14.0    573.   3.358         .516   .520   .549   .571   .596   .623   .651   .661   .660   .252   6
   99.8   172.6   170.6   1111.   5.404   0.000

1.31   175.0   80.6   14.0    462.   2.768         .542   .546   .574   .595   .619   .645   .662   .661   .660   .252   1
   83.6   141.9   165.9   1163.   6.111   0.000

1.41   150.8   70.0   14.0    395.   2.407         .566   .570   .597   .617   .640   .663   .662   .661   .660   .252   5
   70.0   123.3   164.1   1206.   6.369   0.000
10 -1.9745E-03
11 -1.0298E-03

                              L* WARNING AT 37.28

1.51   123.5   57.6   14.0    317.   1.983         [illegible] [illegible] .617 .636 .658 .663 .662 .661 .660 .252   5
   57.6   101.5   159.8   1241.   6.589   0.000
 9 -1.5900E-03

1.61   101.1   47.7   14.0    255.   1.645         .608   .611   .636   .653   .664   .663   .662   .661   .660   .252   6
   47.8    84.1   1 4.8   1273.   6.770   0.000

1.71    81.4   39.0   14.0    199.   1.343         .626   [illegible] .651 .665  .664   .663   .662   .661   .660   .252   6
   39.     68.7   148.3   1292.   6.920   0.000
 6 -1.6695E-03

AVERAGE THRUST AND ISP ARE  723.  84, 186.1 SEC        WITH ACTION TIME OF 1.809 SECONDS
    MAXIMUM THRUST IS  1508. LB, AND MAXIMUM PRESSURE IS 2633.28 PSIA

1.81    59.2   28.6   14.0    134.    .984          .641   .644   .664   .665   .664   .663   .662   .661   .660   .252   7
   28.6    50.3   135.7   1309.   7.036   0.000
 5 -3.3927E-03

1.91    42.0   20.4   14.0     82.    .699          .654   .656   .666   .665   .664   .663   .662   .661   .660   .252   6
   20.4    35.8   117.1   1320.   7.120   0.000

THROAT UNCHOKED

10  3.3052E-02  2.5649E+01  5.6003E-01  1.0000E+00
11  2.0404E-02  2.5679E+01  5.6003E-01  1.0000E+00
12  1.1879E-02  2.5696E+01  5.6003E-01  1.0000E+00

           TAU         G             V            P            A            W            R            RHO
  1  0.          0.            0.           2.5701E+01   2.9854E+00   0.           8.7433E-02   8.1286E-06
  2  0.          3.7634E-02    7.3244E+03   2.4754E+01   2.9842E+00   1.5772E-01   8.5587E-02   7.8524E-06
  3  0.          7.3490E-02    1.6217E+04   2.1597E+01   3.0027E+00   3.1001E-01   7.9165E-02   6.9254E-06
  4  0.          1.0047E-01    3.1544E+04   1.4593E+01   3.0178E+00   4.2571E-01   6.3259E-02   4.8639E-06
  5  0.          1.0058E-01    3.1596E+04   1.4532E+01   3.0172E+00   4.2618E-01   6.3097E-02   4.8451E-06
  6  0.          1.0062E-01    3.1765E+04   1.4491E+01   3.0172E+00   4.2632E-01   6.2998E-02   4.8333E-06
  7  0.          1.0065E-01    3.1875E+04   1.4451E+01   3.0172E+00   4.2646E-01   6.2897E-02   4.8212E-06
  8  0.          1.0068E-01    3.1967E+04   1.4409E+01   3.0172E+00   4.2660E-01   6.2794E-02   4.8089E-06
  9  0.          1.0071E-01    3.2062E+04   1.4367E+01   3.0172E+00   4.2674E-01   6.2686E-02   4.7961E-06
 10  0.          1.0075E-01    3.2160E+04   1.4322E+01   3.0172E+00   4.2688E-01   6.2575E-02   4.7829E-06
 11  0.          1.0078E-01    3.2261E+04   1.4277E+01   3.0172E+00   4.2702E-01   6.2460E-02   4.7693E-06
 12  0.          1.0081E-01    3.2344E+04   1.4241E+01   3.0172E+00   4.2715E-01   6.2384E-02   4.7601E-06
 13  0.          1.0084E-01    3.2430E+04   1.4203E+01   3.0172E+00   4.2729E-01   6.2287E-02   4.7467E-06
 14  0.          1.0087E-01    3.2521E+04   1.4163E+01   3.0172E+00   4.2742E-01   6.2188E-02   4.7365E-06
 15  0.          1.0091E-01    3.2619E+04   1.4120E+01   3.0172E+00   4.2755E-01   6.2074E-02   4.7236E-06
 16  0.          1.0092E-01    3.2709E+04   1.4079E+01   3.0172E+00   4.2763E-01   6.1970E-02   4.7113E-06
 17  0.          1.0094E-01    3.2803E+04   1.4037E+01   3.0172E+00   4.2771E-01   6.1861E-02   4.6985E-06
 19  0.          1.0095E-01    3.2894E+04   1.3995E+01   3.0172E+00   4.2776E-01   6.1754E-02   4.6858E-06
 19  0.          1.0097E-01    3.2990E+04   1.3951E+01   3.0172E+00   4.2781E-01   6.1642E-02   4.6726E-06


              PRESSURE          THRUST   FLOW                                     WEB BURNED / LENGTH
TIME    HEAD    EXIT    PLEN                       0.00   8.00  16.00  20.00  24.00  28.00  32.00  36.00  38.47  40.00  LOOP
     P*      PT*     ISP     IMP     SUM W    DEFL

2.01    25.7   14.0   14.0     34.    .428          .664   .665   .666   .665   .664   .663   .662   .661   .660   .252   13
   14.0    22.1    79.3   1326.   7.176   0.000

2.11    15.3   14.1   14.0      4.    .143          .669   .668   .666   .665   .664   .663   .662   .661   .660   .252   7
   14.1    14.9    28.4   1327.   7.205   0.000

STOP ISP = 192.65, BASED ON LOADED WEIGHT OF      6.9 LBS
```

The normal output at each time increment is printed in two lines under the heading. The error messages headed 10 and 11 indicate that the program was slow to converge the calculation at 0.02 second, and was over-damped. Detail output was requested at 0.1 second in table 6, the first table loaded, and printed before the 0.11-second normal output .

Calculation continues to 1.51 seconds. The L* warning indicates potential instability at that time. Only one message is printed, but the nozzleless motor moves toward the unstable region for the completion of the run.

Between 1.41 and 1.51 seconds, two error messages are printed. In this case, an error of 0.2 and 0.1+ percent in velocity was accepted, where 0.1 percent was requested, at nodes 10 and 11, respectively.

Motor action time is sensed at 1.81 seconds as the thrust drops to 10 percent of peak thrust. A summary printout of average thrust and I_{sp} is printed ahead of the normal output for that time increment. The throat unchokes prior to the 2.01-second increment, and burnout is sensed after 2.11 seconds as head pressure falls to within 2 psi of ambient pressure.

The next three sample cases (Table V-2) were run as a single machine access to illustrate the input of changes after one case is run. Also, the input data is simplified to the parameters required for the specific examples.

The first case in the batch is a 5- by 40-inch motor with a 1-inch bore and a cone to 2 inches in the last 2 inches of the motor as input in table 3. The ignition time option is keyed by NUM(6) = 1 input in the card labeled CONTROLS. The ignition time is input as the first increment in the Δt table, table 5. An igniter mass flow is not normally consistent with starting with the motor "on" at equilibrium, so is not input; the note of the missing table is printed on the second page.

The summary of control words verifies that the ignition time option is set and that the fraction of aluminum burned calculations are set. Note that grain deflection is not to be considered, and also that no data was given (Z(26) - Z(28) or table 7).

At this point, it is convenient to note that the user may utilize the "UNCORRELATED TABLE" notes that signal a missing table (11, 7, 2, and 16 in this example) or may input a 1 x 1 table with Z = 0 to avoid the notes. The resulting calculation is unchanged. As calculation begins, the remaining two missing tables are inspected and the throat is located at node 17.

The first printout time occurs at 0.03 second, as expected. The calculation assumes no capacitance term in the continuity equation ($\frac{\partial \rho A}{\partial t} = 0$) with this option, but requires input knowledge of the time to peak pressure.

(The reverse is blank)

TABLE V-2

SAMPLE BATCH OUTPUT LISTING

```
5 X 40 INCH NOZZLELESS MOTOR WITH EXIT CONE

LOGIC          BASE BURN RATE
          1    1             3    1              6    6             -1
 DATA     1   15.000000      0   30.000000       0  100.000000       0  200.000000       0 1000.000000       0 3000.000000  -1
 DATA     1    0.060000      0    0.180000       0    0.320000       0    0.460000       0    1.000000       0    1.500000  -1

LOGIC          MOTOR GEOMETRY
          1    3             5    2              0    3             -1
 DATA     1    1.000000      0    2.000000      -1
 DATA     1    0.0           0   38.000000       0   40.000000      -1
 DATA     1    1.000000      0    1.000000       0    2.000000      -1
 DATA     1    5.000000      0    5.000000       0    5.000000      -1

LOGIC          AXIAL INCREMENT SPACING
          1    4             6    4             -1
 DATA     1    0.390000      0    0.400000       0    0.890000       0    0.900000      -1
 DATA     1    1.799999      0    0.900000       0    0.900000       0    0.450000      -1

LOGIC          TIME INCREMENTS
          1    5             6    3             -1
 DATA     1    0.0           0    0.030000       0    0.100000      -1
 DATA     1    0.030000      0    0.070000       0    0.100000      -1

LOGIC          PRINT TIMES
          1    6             6    5             -1
 DATA     1    0.0           0    1.000000       0    2.000000       0    3.000000      -1
 DATA     1    0.100000      0    1.000000       0    4.500000       0  100.000000      -1

LOGIC          THERMOCHEMISTRY
          1    8             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1 3000.000000      0 3400.000000      -1

LOGIC
          1    9             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1   11.000000      0   11.799999      -1

LOGIC
          1   10             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1    9.799999      0    9.200000      -1

LOGIC
          1   13             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1    3.500000      0    3.599999      -1

LOGIC
          1   14             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1    4.000000      0    3.900000      -1

LOGIC
          1   15             6    2             -1
 DATA     1    0.500000      0    1.000000      -1
 DATA     1   20.500000      0   18.500000      -1

LOGIC          CONTROLS
         10   16             0



LOGIC          CONTROLS
          1   19             0    1              4   -1              6    1            -1
 DATA     1   10.000000      4   53.000000       0    0.000004       7   40.000000      3    0.200000      0
 DATA    20    0.000500      0    1.000000       0 2500.000000       0    0.000100      0   14.000000      0    0.550000    0
 DATA    30    0.620000     32    0.178400      34    0.800000      36    0.064000     29    1.000000      0
 DATA    38   20.000000      0    0.947000       0    0.554300      -1
 REFERENCE TO UNCORRELATED TABLE NUMBER   11    0

EROSION MODEL NO 1 FOR PROPELLANT 1          RHO = 0.0640     K1 = 0.6280     K2 = 0.1784     EXP = 0.80     TO LENGTH =   0.0 IN.

 REFERENCE TO UNCORRELATED TABLE NUMBER    7    0


 NOMINAL GEOMETRY
                   HEAD     THROAT      EXIT

 LENGTH                      40.00     40.00
 INNER DIAM        1.00       2.00      2.00
 OUTER DIAM        5.00       5.00      5.00

 DETAILED GRAIN DESIGN INPUT IN TABLE 3 TO USE 19 NODES SPACED AS INPUT IN TABLE 4


 CONTROL WORDS IN INPUT (NON-ZERO IS KEY)
          PARAMETRIC VARIATION KEY    0        XRAY NODE NO 15
          IGNITION INPUT DT OPTION    1
          2-DIMENSIONAL GRAIN KEY  0.0    (HIGH)
          N-POINT STAR GRAIN KEY   0.0    (WIDE)
          FUSE IGNITION CONTROL       0.0 (RATE)
          HEAD-END DOME DESIGN        0.0
          PLENUM-THROAT CALC, P =     0.0
          FRACTION BURNED KEY D =    20.0 MICRONS
          GRAIN DEFLECTION KEY WN     0.0
```

PRESSURE			THRUST	FLOW		WEB BURNED / LENGTH										
TIME	HEAD	EXIT	PLEN			0.0	8.00	15.00	20.00	24.00	28.00	32.00	36.00	38.00	40.00	LOOP
PO	PTO	ISP	IMP	SUM W	DEFL											

REFERENCE TO UNCORRELATED TABLE NUMBER 2 0

REFERENCE TO UNCORRELATED TABLE NUMBER 16 0

THROAT LOCATION AT NODE 17 AT LENGTH 38.0 IN. SLOPE = 1.01

0.03	2580.7	14.9	14.0	4587.	13.839	0.043	0.044	0.047	0.049	0.051	0.053	0.056	0.058	0.060	0.018	11
1222.9	2144.8	331.5	69.	5.700	0.0											

	TAU	G	V	P	A	M	R	RHO
1	0.0	0.0	0.0	1.8660E 03	1.2719E 00	0.0	1.2589E 00	4.9877E-04
2	0.0	6.8949E-01	2.1087E 03	1.8607E 03	1.2739E 00	1.2852E 00	1.2598E 00	4.9746E-04
3	9.6233E-04	1.3751E 00	4.2393E 03	1.8447E 03	1.2877E 00	2.5910E 00	1.2887E 00	4.9349E-04
4	5.2379E-03	2.0619E 00	6.4460E 03	1.8170E 03	1.3055E 00	3.9386E 00	1.3255E 00	4.8665E-04
5	1.3956E-02	2.7506E 00	8.7809E 03	1.7763E 03	1.3261E 00	5.3371E 00	1.3671E 00	4.7657E-04
6	1.9921E-02	3.0956E 00	1.0017E 04	1.7504E 03	1.3373E 00	6.0573E 00	1.3895E 00	4.7015E-04
7	2.7125E-02	3.4411E 00	1.1315E 04	1.7203E 03	1.3491E 00	6.7928E 00	1.4126E 00	4.6269E-04
8	3.5652E-02	3.7870E 00	1.2689E 04	1.6855E 03	1.3615E 00	7.5441E 00	1.4363E 00	4.5405E-04
9	4.5620E-02	4.1332E 00	1.4160E 04	1.6452E 03	1.3744E 00	8.3120E 00	1.4606E 00	4.4408E-04
10	5.7208E-02	4.4797E 00	1.5757E 04	1.5987E 03	1.3879E 00	9.0973E 00	1.4855E 00	4.3253E-04
11	7.0689E-02	4.8262E 00	1.7520E 04	1.5446E 03	1.4020E 00	9.9006E 00	1.5108E 00	4.1909E-04
12	8.6497E-02	5.1726E 00	1.9515E 04	1.4808E 03	1.4168E 00	1.0723E 01	1.5366E 00	4.0326E-04
13	1.0539E-01	5.5187E 00	2.1851E 04	1.4042E 03	1.4321E 00	1.1564E 01	1.5626E 00	3.8424E-04
14	1.2884E-01	5.8641E 00	2.4750E 04	1.3085E 03	1.4482E 00	1.2426E 01	1.5886E 00	3.6047E-04
15	1.6071E-01	6.2084E 00	2.8796E 04	1.1778E 03	1.4651E 00	1.3309E 01	1.6139E 00	3.2801E-04
16	1.8291E-01	6.3800E 00	3.1863E 04	1.0[illegible]35E 03	1.4739E 00	1.3759E 01	1.6255E 00	3.0463E-04
17	2.3489E-01	6.5614E 00	3.9529E 04	8.7247E 02	1.4804E 00	1.4212E 01	1.6175E 00	2.5253E-04
18	1.9584E-01	4.2840E 00	6.3945E 04	3.0443E 02	2.3329E 00	1.4624E 01	1.1374E 00	1.0191E-04
19	1.1695E-01	2.8574E 00	7.2910E 04	1.6543E 02	3.5763E 00	1.4953E 01	8.0289E-01	[illegible].9768E-05

PRESSURE			THRUST	FLOW		WEB BURNED / LENGTH										
TIME	HEAD	EXIT	PLEN			0.0	8.00	16.00	20.00	24.00	28.00	32.00	36.00	38.00	40.00	LOOP
PO	PTO	ISP	IMP	SUM W	DEFL											
0.10	1868.0	165.4	14.0	3241.	14.953	0.136	0.140	0.150	0.155	0.161	0.168	0.175	0.183	0.186	0.067	7
872.5	1532.2	216.8	343.	1.215	0.0											
.20	1297.2	164.9	14.0	3173.	15.282	0.254	0.260	0.277	0.286	0.296	0.307	0.318	0.328	0.331	0.144	3
603.6	1061.4	207.6	664.	2.727	0.0											
0.30	991.7	158.7	14.0	3080.	15.255	0.359	0.366	0.387	0.398	0.411	0.424	0.437	0.448	0.447	0.216	6
463.5	813.8	201.9	976.	4.254	0.0											
0.40	798.2	150.3	14.0	2973.	15.062	0.454	0.461	0.484	0.498	0.512	0.526	0.539	0.550	0.548	0.283	6
374.8	657.8	197.4	1279.	5.770	0.0											
0.50	663.5	141.8	14.0	2858.	14.756	0.540	0.546	0.572	0.586	0.601	0.616	0.630	0.639	0.632	0.345	7
312.7	549.2	193.7	1570.	7.26[illegible]	0.0											
0.60	567.5	131.9	14.0	2758.	4.467	0.619	0.625	0.651	0.667	0.682	0.697	0.711	0.720	0.709	0.401	7
268.8	471.8	190.7	1851.	8.72	0.0											
0.70	496.8	125.3	14.0	2676.	14.[illegible]2	0.692	0.698	0.725	0.741	0.757	0.772	0.786	0.793	0.779	0.454	7
236.4	414.7	188.0	2123.	10.157	0.0											
0.80	442.8	119.9	14.0	2610.	14.051	0.762	0.767	0.793	0.810	0.826	0.842	0.855	0.861	0.843	0.503	8
211.5	371.2	185.8	2387.	11.571	0.0											
0.90	400.5	115.3	14.0	2558.	13.916	0.828	0.832	0.858	0.875	0.891	0.907	0.919	0.924	0.902	0.550	8
192.1	337.0	183.8	2646.	12.969	0.0											

	TAU	G	V	P	A	M	R	RHO
1	0.0	0.0	0.0	3.6640E 02	6.0760E 00	0.0	6.1605E-01	1.0263E-04
2	0.0	1.5838E-01	2.3135E 03	3.6504E 02	6.0710E 00	1.3772E 00	6.1499E-01	1.0229E-04
3	0.0	3.1439E-01	4.6383E 03	3.6118E 02	6.1109E 00	2.7518E 00	6.1180E-01	1.0128E-04
4	0.0	4.6442E-01	6.9570E 03	3.5472E 02	6.2002E 00	4.1244E 00	6.0649E-01	9.9602E-05
5	0.0	6.0635E-01	9.3127E 03	3.4575E 02	6.3290E 00	5.4967E 00	5.9904E-01	9.7286E-05
6	0.0	6.7435E-01	1.0509E 04	3.4039E 02	6.4036E 00	6.1852E 00	5.9831E-01	9.5880E-05
7	0.0	7.4115E-01	1.1744E 04	3.3428E 02	6.4795E 00	6.8784E 00	5.9849E-01	9.4293E-05
8	0.0	8.0698E-01	1.3034E 04	3.2741E 02	6.5552E 00	7.5767E 00	5.9918E-01	9.2507E-05
9	0.0	8.7190E-01	1.4395E 04	3.1969E 02	6.6297E 00	8.2795E 00	5.9934E-01	9.0498E-05
10	0.0	9.3613E-01	1.5852E 04	3.1100E 02	6.7019E 00	8.9862E 00	5.9887E-01	8.8237E-05
11	0.0	9.9985E-01	1.7437E 04	3.0116E 02	6.7704E 00	9.6960E 00	5.9770E-01	8.5676E-05
12	9.4428E-03	1.0634E 00	1.9203E 04	2.8988E 02	6.8332E 00	1.0408E 01	5.9567E-01	8.2739E-05
13	1.2122E-02	1.1277E 00	2.1249E 04	2.7660E 02	6.8843E 00	1.1119E 01	5.9242E-01	7.9292E-05
14	1.5609E-02	1.1918E 00	2.3755E 04	2.6041E 02	6.9176E 00	1.1829E 01	5.8731E-01	7.5090E-05
15	2.0589E-02	1.2648E 00	2.7186E 04	2.3883E 02	6.9184E 00	1.2531E 01	5.7862E-01	6.9502E-05
16	2.4483E-02	1.3048E 00	2.9747E 04	2.2348E 02	6.8901E 00	1.2877E 01	5.7119E-01	6.5540E-05
17	3.7245E-02	1.3808E 00	3.8595E 04	1.7630E 02	6.6742E 00	1.3210E 01	5.3878E-01	5.3454E-05
18	4.1223E-02	1.3765E 00	4.4205E 04	1.4453E 02	7.1167E 00	1.3521E 01	4.9625E-01	4.4878E-05
19	4.2043E-02	1.2074E 00	5.0573E 04	1.1097E 02	[illegible].9878E 00	1.3814E 01	4.3506E-01	3.5685E-05

```
               PRESSURE          THRUST    FLOW                          WEB BURNED / LENGTH
TIME     HEAD     EXIT     PLEN                    0.0    8.00   16.00  20.00  24.00  28.00  32.00  36.00  38.00  40.00  [illegible]
    PC       PTO      ISP      IMP     SUM W     DEPL

1.00    366.4    111.0    14.0    2514.   13.814       0.891  0.895  0.919  0.936  0.953  0.968  0.980  0.984  0.958  0.595    9
   176.1    309.4    187.0    2899.   14.356    0.0
1.10    338.4    107.6    14.0    2479.   13.740       0.951  0.955  0.978  0.995  1.011  1.026  1.038  1.040  1.010  0.637    9
   163.3    286.8    180.4    3149.   15.733    0.0
1.20    314.9    104.6    14.0    2451.   13.691       1.009  1.013  1.035  1.051  1.067  1.082  1.093  1.094  1.060  0.678    9
   152.6    267.8    179.0    3395.   17.105    0.0
1.30    295.1    101.9    14.0    2430.   13.667       1.066  1.069  1.090  1.105  1.121  1.136  1.146  1.146  1.107  0.718    9
   143.5    251.8    177.8    3639.   18.473    0.0
THROAT LOCATION AT NODE 10 AT LENGTH 39.0 IN,  SLOPE =  0.77

1.40    278.     99.2     14.0    2412.   13.651       1.121  1.123  1.143  1.157  1.173  1.187  1.197  1.195  1.152  0.757    9
   132.6    232.8    176.7    3882.   19.839    0.0
1.50    263.8    97.2     14.0    2401.   13.664       1.174  1.176  1.195  1.208  1.223  1.237  1.246  1.242  1.196  0.794    9
   126.2    221.7    175.7    4122.   21.205    0.0
1.60    251.1    95.3     14.0    2392.   13.684       1.226  1.227  1.245  1.258  1.272  1.285  1.296  1.288  1.238  0.830    8
   120.7    211.9    174.8    4362.   22.572    0.0
1.70    239.8    93.7     14.0    2386.   13.712       1.277  1.278  1.295  1.337  1.319  1.332  1.340  1.333  1.279  0.866    8
   115.8    203.1    174.0    4601.   23.942    0.0
1.80    229.7    92.2     14.0    2380.   13.745       1.326  1.327  1.343  1.354  1.368  1.377  1.384  1.376  1.319  0.901    9
   111.2    195.3    173.2    4839.   25.314    0.0
1.90    220.6    91.1     14.0    2377.   13.784       1.375  1.376  1.391  1.401  1.412  1.422  1.428  1.418  1.357  0.935    9
   107.2    188.2    172.5    5077.   26.691    0.0
2.00    212.4    90.0     14.0    2376.   13.828       1.423  1.423  1.437  1.447  1.457  1.465  1.470  1.458  1.395  0.968    9
   103.6    181.8    171.8    5315.   28.072    0.0
2.10    204.9    89.4     14.0    2375.   13.874       1.470  1.470  1.483  1.492  1.501  1.508  1.511  1.498  1.431  1.001    9
   100.3    175.9    171.2    5552.   29.457    0.0
2.20    198.0    90.0     14.0    2375.   13.920       1.516  1.516  1.528  1.536  1.544  1.550  1.552  1.537  1.467  1.034   10
    97.1    170.5    170.6    5790.   30.846    0.0
2.30    191.8    90.8     14.0    2371.   13.967       1.561  1.561  1.572  1.579  1.586  1.592  1.592  1.575  1.502  1.066   10
    94.2    165.4    169.9    6027.   32.241    0.0
2.40    186.2    89.3     14.0    2375.   14.012       1.606  1.605  1.615  1.622  1.628  1.632  1.631  1.612  1.536  1.098    1
    89.3    157.5    169.5    6264.   33.640    0.0
2.50    180.5    87.7     14.0    2382.   14.072       1.650  1.649  1.658  1.664  1.670  1.672  1.669  1.648  1.570  1.129   10
    87.7    153.8    169.3    6502.   35.044    0.0
2.60    175.7    85.5     14.0    2388.   14.142       1.693  1.692  1.700  1.706  1.710  1.712  1.707  1.684  1.603  1.160    9
    85.5    150.2    168.8    6741.   36.454    0.0
2.70    171.2    83.6     14.0    2394.   14.210       1.736  1.734  1.742  1.747  1.750  1.751  1.745  1.720  1.636  1.190    9
    83.6    146.8    168.4    6980.   37.872    0.0


2.80    166.9    81.8     14.0    2399.   14.278       1.778  1.776  1.783  1.787  1.790  1.790  1.782  1.755  1.668  1.220    9
    81.8    143.5    168.0    7219.   39.296    0.0
2.90    162.9    80.0     14.0    2405.   14.347       1.819  1.817  1.824  1.827  1.829  1.828  1.819  1.789  1.699  1.249   10
    80.0    140.5    167.6    7460.   40.728    0.0
3.00    159.2    78.4     14.0    2411.   14.416       1.860  1.858  1.864  1.867  1.868  1.865  1.855  1.824  1.730  1.278    9
    78.4    137.6    167.3    7700.   42.166    0.0
3.10    155.6    76.8     14.0    2417.   14.486       1.901  1.899  1.903  1.906  1.906  1.903  1.891  1.858  1.761  1.306   10
    76.8    134.9    166.9    7942.   43.611    0.0
3.20    152.3    75.4     14.0    2424.   14.559       1.941  1.938  1.942  1.944  1.944  1.940  1.927  1.891  1.791  1.334   10
    75.4    132.3    166.5    8184.   45.063    0.0
3.30    149.1    74.0     14.0    2431.   14.632       1.981  1.978  1.981  1.982   .981  1.976  1.962  1.924  1.822  1.362   10
    74.0    129.8    166.1    8427.   46.523    0.0
L* WARNING SUPPRESSED DURING TAILOFF

3.40    91.0     45.1     14.0    1413.   9.167        2.000  2.000  2.000  2.000  2.000  2.000  1.994  1.954  1.849  1.387    1
    45.3    79.5     154.2    8619.   47.713    0.0
THROAT UNCHOKED

AVERAGE THRUST AND ISP ARE 2484. LBF, 180.2 SEC          WITH ACTION TIME OF 3.400 SECONDS
   MAXIMUM THRUST IS  4587. LB, AND MAXIMUM PRESSURE IS 2580.70 PSIA

3.50    17.4     14.0     14.0    63.     1.390        2.000  2.000  2.000  2.000  2.000  2.000  2.000  1.971  1.864  1.401    3
    14.0    16.2     45.0     8693.   48.240    0.0
3.60    14.3     13.9     14.0    4.      0.381        2.000  2.000  2.000  2.000  2.000  2.000  2.000  1.978  1.870  1.407    0
    13.9    14.1     10.0     8696.   48.329    0.0

STOP ISP = 180.73, BASED ON LOADED WEIGHT OF     48.1 LBS
```

```
REVISIONS TO 5 X 40 INCH MOTOR WITH TWO PROPELLANTS

LOGIC            BASE BURN RATE
           1      1              3     1              6     6              5     2              -1
 DATA      1      1.000000       0     2.000000      -1
 DATA      1     15.000000       0    30.000000       0   100.000000       0   200.000000       0  1000.000000       0  3000.000000  -1
 DATA      1      0.060000       0     0.180000       0     0.320000       0     0.460000       0     1.000000       0     1.500000  -1
 DATA      1      0.030000       0     0.090000       0     0.160000       0     0.230000       0     0.500000       0     0.750000  -1

LOGIC            MOTOR GEOMETRY
           1      3              5     2             -1
 DATA      1      1.000000       0     2.000000      -1
 DATA      1      0.0           -1                    -
 DATA      1      1.000000      -1
 DATA      1      5.000000      -1

LOGIC            CONTROLS
           6     -1              3     1             -1
 DATA      6     36.000000      31     0.628000      33     0.178400      35     0.800000      37     0.064000      -1
EROSION MODEL NO 1 FOR PROPELLANT 1            RHO = 0.0640     K1 = 0.6280     K2 = 0.1784     EXP = 0.80     TO LENGTH = 36.0 IN.
EROSION MODEL NO 1 FOR PROPELLANT 2            RHO = 0.0640     K1 = 0.6280     K2 = 0.1784     EXP = 0.80     TO LENGTH = 40.0 IN.

 NOMINAL GEOMETRY
                  HEAD     THROAT      EXIT

 LENGTH                     40.00     40.00
 INNER DIAM       1.00       1.00      1.00
 OUTER DIAM       5.00       5.00      5.00

 DETAILED GRAIN DESIGN INPUT IN TABLE 3 TO USE 19 NODES SPACED AS INPUT IN TABLE 4


 CONTROL WORDS IN INPUT (NON-ZERO IS KEY)
          PARAMETRIC VARIATION KEY   0        XRAY NODE NO 15
          IGNITION INPUT DT OPTION   1
          2-DIMENSIONAL GRAIN KEY  0.0   (HIGH)
          N-POINT STAR GRAIN KEY   0.0   (WIDE)
          FUSE IGN  ION CONTROL      0.0 (RATE)
          HEAD-END DOME DESIGN       0.0
          PLENUM-THROAT CALC, P =    0.0
          FRACTION BURNED KEY D =   20.0 MICRONS
          GRAIN DEFLECTION KEY WN    0.0



            PRESSURE          THRUST   FLOW                                              WEB BURNED / LENGTH
TIME     HEAD     EXIT     PLEN                            0.0     8.00   16.00   20.00   24.00   28.00   32.00   36.00   38.00   40.00  LOOP
     P*        PT*     ISP       IMP     SUM W     DEFL


0.03  2841.0  1370.4    14.0    2667.  14.053          0.044   0.045   0.049   0.050   0.053   0.055   0.057   0.060   0.044   0.047    16
  1370.4  2402.9    189.8       40.   0.211   0.0
```

	TAU	G	V	P	A	W	R	RHO
1	0.0	0.0	0.0	2.1694E 03	1.2954E 00	0.0	1.3309E 00	5.7770E-04
2	0.0	7.1033E-01	1.8800E 03	2.1646E 03	1.2977E 00	1.3518E 00	1.3325E 00	5.7651E-04
3	8.2506E-04	1.4165E 00	3.7728E 03	2.1498E 03	1.3117E 00	2.7249E 00	1.3612E 00	5.7288E-04
4	4.5048E-03	2.1233E 00	5.7172E 03	2.1246E 03	1.3297E 00	4.1404E 00	1.3978E 00	5.6666E-04
5	1.2102E-02	2.8312E 00	7.7473E 03	2.0878E 03	1.3505E 00	5.6072E 00	1.4393E 00	5.5759E-04
6	1.7297E-02	3.1854E 00	8.8072E 03	2.0646E 03	1.3619E 00	6.3619E 00	1.4615E 00	5.5187E-04
7	2.3539E-02	3.5400E 00	9.9057E 03	2.0379E 03	1.3738E 00	7.1319E 00	1.4844E 00	5.4527E-04
8	3.0868E-02	3.8947E 00	1.1051E 04	2.0074E 03	1.3864E 00	7.9181E 00	1.5082E 00	5.3772E-04
9	3.9341E-02	4.2495E 00	1.2254E 04	1.9726E 03	1.3994E 00	8.7211E 00	1.5325E 00	5.2912E-04
10	4.9035E-02	4.6044E 00	1.3527E 04	1.9330E 03	1.4131E 00	9.5416E 00	1.5575E 00	5.1334E-04
11	6.0066E-02	4.9590E 00	1.4888E 04	1.8881E 03	1.4274E 00	1.0380E 01	1.5830E 00	5.0822E-04
12	7.2601E-02	5.3133E 00	1.6360E 04	1.8364E 03	1.4423E 00	1.1238E 01	1.6091E 00	4.9553E-04
13	8.6888E-02	5.6670E 00	1.7977E 04	1.7780E 03	1.4579E 00	1.2116E 01	1.6356E 00	4.8098E-04
14	1.0331E-01	6.0197E 00	1.9790E 04	1.7099E 03	1.4743E 00	1.3014E 01	1.6626E 00	4.6412E-04
15	1.2249E-01	6.3709E 00	2.1882E 04	1.62[illegible]7E 03	1.4915E 00	1.3934E 01	1.6899E 00	4.4424E-04
16	2.3508E-01	7.6412E 00	2.9821E 04	1.4052E 03	1.2787E 00	1.4328E 01	1.2484E 00	3.9097E-04
17	2.6308E-01	7.7493E 00	3.1740E 04	1.3309E 03	1.2896E 00	1.4655E 01	1.2679E 00	3.7252E-04
18	2.9430E-01	7.8478E 00	3.4368E 04	1.2337E 03	1.3024E 00	1.4988E 01	1.2901E 00	3.4841E-04
19	3.4359E-01	7.9079E 00	3.9554E 04	1.0584E 03	1.3221E 00	1.5332E 01	1.3206E 00	3.0505E-04

	PRESSURE			THRUST	FLOW	WEB BURNED / LENGTH										
TIME	HEAD	EXIT	PLEN			0.0	8.00	16.00	20.00	24.00	28.00	32.00	36.00	38.00	40.00	LOOP
PO	PTE	ISP	IMP	SUM W	DEFL											
0.10	2169.4	1058.4	14.0	2895.	15.332	0.142	0.146	0.156	0.161	0.167	0.174	0.181	0.189	0.141	0.149	11
1058.4	1855.9	188.8	235.	1.239	0.0											
0.20	1593.2	787.2	14.0	3015.	16.068	0.268	0.274	0.291	0.300	0.310	0.321	0.332	0.344	0.256	0.268	10
787.2	1380.4	187.6	530.	2.809	0.0											
0.30	1275.5	637.0	14.0	3105.	16.633	0.382	0.390	0.410	0.423	0.436	0.449	0.463	0.478	0.354	0.367	12
637.0	1118.2	186.7	838.	4.444	0.0											
0.40	1077.0	543.4	14.0	3143.	17.177	0.488	0.496	0.521	0.535	0.550	0.565	0.581	0.598	0.439	0.453	12
543.4	953.8	185.9	1151.	6.135	0.0											
0.50	935.7	476.1	14.0	3261.	17.607	0.588	0.596	0.623	0.639	0.655	0.672	0.689	0.707	0.516	0.529	12
476.1	835.7	185.2	1474.	7.874	0.0											
0.60	825.5	423.4	14.0	3297.	17.866	0.682	0.689	0.719	0.735	0.753	0.771	0.789	0.807	0.585	0.599	11
423.4	742.5	184.6	1802.	9.648	0.0											
0.70	738.6	380.7	14.0	3317.	18.033	0.771	0.778	0.808	0.826	0.844	0.863	0.882	0.901	0.650	0.663	11
380.7	668.5	183.9	2132.	11.443	0.0											
0.80	669.5	347.3	14.0	3332.	18.172	0.855	0.862	0.893	0.911	0.931	0.950	0.969	0.989	0.709	0.722	11
347.3	609.3	183.4	2465.	13.253	0.0											
0.90	613.9	319.9	14.0	3347.	18.310	0.936	0.942	0.973	0.992	1.012	1.032	1.052	1.072	0.765	0.777	11
319.9	561.5	182.8	2799.	15.077	0.0											

	TAU	G	V	P	A	W	R	RHO
1	0.0	0.0	0.0	5.6843E 02	7.1966E 00	0.0	7.6145E-01	1.5709E-04
2	0.0	1.7788E-01	1.6998E 03	5.6736E 02	7.1957E 00	1.8430E 00	7.6075E-01	1.5681E-04
3	0.0	3.5297E-01	3.3908E 03	5.6412E 02	7.2530E 00	3.6863E 00	7.5865E-01	1.5599E-04
4	0.0	5.2112E-01	5.0497E 03	5.5885E 02	7.3761E 00	5.5348E 00	7.5522E-01	1.5464E-04
5	0.0	6.8062E-01	6.6745E 03	5.5169E 02	7.5496E 00	7.3988E 00	7.5393E-01	1.5280E-04
6	0.0	7.5771E-01	7.4844E 03	5.4741E 02	7.6453E 00	8.3413E 00	7.5647E-01	1.5171E-04
7	0.0	8.3343E-01	8.2992E 03	5.4264E 02	7.7440E 00	9.2934E [illegible]	7.5902E-01	1.5048E-04
8	0.0	9.0784E-01	9.1219E 03	5.3739E 02	7.8450E 00	1.0255E 01	7.6152E-01	1.4913E-04
9	0.0	9.8108E-01	9.9567E 03	5.3163E 02	7.9469E 00	1.1226E 01	7.6395E-01	1.4765E-04
10	3.1381E-03	1.0532E 00	1.0807E 04	5.2534E 02	8.0494E 00	1.2207E 01	7.6626E-01	1.4604E-04
11	4.0057E-03	1.1242E 00	1.1676E 04	5.1850E 02	8.1526E 00	1.3197E 01	7.6842E-01	1.4428E-04
12	5.1921E-03	1.1942E 00	1.2569E 04	5.1109E 02	8.2562E 00	1.4197E 01	7.7039E-01	1.4237E-04
13	6.4353E-03	1.2632E 00	1.3491E 04	5.0306E 02	8.3597E 00	1.5205E 01	7.7215E-01	1.4031E-04
14	7.8559E-03	1.3313E 00	1.4449E 04	4.9436E 02	8.4627E 00	1.6222E 01	7.7366E-01	1.3807E-04
15	9.4583E-03	1.3988E 00	1.5451E 04	4.8493E 02	8.5646E 00	1.7248E 01	7.7488E-01	1.3564E-04
16	6.5819E-02	2.2687E 00	3.1416E 04	3.7214E 02	5.4001E 00	1.7641E 01	5.0881E-01	1.0822E-04
17	7.5659E-02	2.2834E 00	3.2893E 04	3.5593E 02	5.4479E 00	1.7912E 01	5.0846E-01	1.0402E-04
18	8.5524E-02	2.2973E 00	3.4097E 04	3.3508E 02	5.4972E 00	1.8184E 01	5.0749E-01	9.8649E-05
19	9.9404E-02	2.3087E 00	3.8843E 04	2.9765E 02	5.5522E 00	1.8457E 01	5.0417E-01	8.9065E-05

1.00	568.4	297.6	14.0	3365.	18.457	1.014	1.019	1.050	1.070	1.090	1.111	1.131	1.151	0.817	0.829	11
297.6	522.2	182.3	3135.	16.915	0.0											
1.10	530.5	278.9	14.0	3384.	18.609	1.088	1.094	1.124	1.145	1.165	1.186	1.207	1.227	0.866	0.879	11
278.9	489.3	181.7	3472.	18.769	0.0											
1.20	498.3	263.0	14.0	3405.	18.767	1.161	1.166	1.196	1.216	1.238	1.259	1.280	1.300	0.914	0.925	11
263.0	461.4	181.4	3811.	20.637	0.0											
1.30	471.8	249.3	14.0	3427.	18.932	1.231	1.237	1.265	1.286	1.307	1.329	1.350	1.371	0.959	0.970	11
249.3	437.4	181.0	4153.	22.522	0.0											
1.40	446.9	237.5	14.0	3450.	19.103	1.300	1.305	1.333	1.353	1.375	1.397	1.418	1.439	1.002	1.013	11
237.5	416.5	180.6	4497.	24.424	0.0											
1.50	426.0	227.0	14.0	3475.	19.279	1.367	1.372	1.399	1.419	1.441	1.463	1.485	1.505	1.044	1.054	11
227.0	398.2	180.2	4843.	26.343	0.0											
1.60	407.5	217.8	14.0	3500.	19.458	1.433	1.437	1.464	1.483	1.505	1.527	1.549	1.570	1.084	1.093	11
217.8	382.0	179.9	5192.	28.280	0.0											
1.70	391.1	209.6	14.0	3527.	19.641	1.497	1.501	1.527	1.546	1.568	1.590	1.612	1.633	1.123	1.132	11
209.6	367.6	179.6	5543.	30.235	0.0											
1.80	376.4	202.1	14.0	3554.	19.828	1.560	1.564	1.590	1.608	1.629	1.652	1.673	1.694	1.161	1.169	11
202.1	354.7	179.2	5897.	32.208	0.0											
1.90	363.1	195.5	14.0	3582.	20.017	1.622	1.626	1.651	1.669	1.689	1.712	1.734	1.754	1.198	1.205	11
195.5	343.0	178.9	6254.	34.201	0.0											
2.00	351.1	189.5	14.0	3610.	20.209	1.683	1.686	1.711	1.729	1.749	1.771	1.793	1.813	1.233	1.240	11
189.5	332.4	178.6	6614.	36.212	0.0											
2.10	340.1	184.0	14.0	3639.	20.404	1.743	1.746	1.770	1.787	1.807	1.828	1.850	1.871	1.268	1.274	11
184.0	322.7	178.4	6976.	38.242	0.0											
2.20	330.2	178.8	14.0	3669.	20.601	1.802	1.805	1.828	1.845	1.865	1.885	1.907	1.928	1.302	1.307	12
178.8	313.9	178.1	7341.	40.293	0.0											
2.30	321.0	174.2	14.0	3699.	20.801	1.860	1.863	1.886	1.903	1.921	1.942	1.963	1.984	1.335	1.340	12
174.2	305.8	177.8	7710.	42.363	0.0											
2.40	285.4	155.0	14.0	3381.	19.141	1.916	1.919	1.942	1.958	1.976	1.996	2.000	2.000	1.367	1.370	13
155.0	272.1	176.6	8064.	44.360	0.0											
2.50	180.9	98.3	14.0	2132.	12.481	1.965	1.968	1.990	2.000	2.000	2.000	2.000	2.000	1.391	1.394	14
98.3	172.5	170.8	8339.	45.941	0.0											

LP WARNING SUPPRESSED DURING TAILOFF

2.60	76.7	41.8	14.0	817.	5.399	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	1.407	1.408	12
41.8	73.4	151.3	8487.	46.835	0.0											

THROAT UNCHOKED

```
AVERAGE THRUST AND ISP ARE 3159. LBM, 181.0 SEC        WITH ACTION TIME OF 2.700 SECONDS
    MAXIMUM THRUST IS  3699. LB, AND MAXIMUM PRESSURE IS 2841.5P PSIA

2.70    14.0    14.0    14.0      7.   0.369          2.000  2.000  2.000  2.000  2.000  2.000  2.000  2.000  1.414  1.415     3
    14.0    14.4    16.7   8528.  47.123   0.0

STOP ISP = 176.73, BASED ON LOADED WEIGHT OF    48.3 LBS


5 X 40 WITH FUSE IGNITION

LOGIC            MOTOR GEOMETRY
                  3              5    2              -1
DATA       1      1.000000       0    2.000000       -1
DATA       1      0.0           -1
DATA       1      0.125000      -1
DATA       1      5.000000      -1

LOGIC
       4    -1                   9    19             6    -1              -1
DATA       1      5.000000       6    -0.001000     15    50.000000       0    0.001000      2    0.800000      0
DATA      22      14.000000     -1
EROSION MODEL NO 1 FOR PROPELLANT 1          RHO = 0.0640     K1 = 0.6200     K2 = 0.1784     EXP = 0.80     TO LENGTH = -C.0 IN.

NOMINAL GEOMETRY
                  HEAD      THROAT      EXIT

LENGTH                      40.00      40.00
INNER DIAM        0.13       0.13       0.13
OUTER DIAM        5.00       5.00       5.00

DETAILED GRAIN DESIGN INPUT IN TABLE 3 TO USE 19 NODES SPACED AS INPUT IN TABLE 4


CONTROL WORDS IN INPUT (NON-ZERO IS KEY)
          PARAMETRIC VARIATION KEY    0       XRAY NODE NO 15
          IGNITION INPUT OT OPTION  -1
          2-DIMENSIONAL GRAIN KEY  0.0   (HIGH)
          N-POINT STAR GRAIN KEY   0.0   (WIDE)
          FUSE IGNITION CONTROL     50.0 (RATE)
          HEAD-END DOME DESIGN       0.0
          PLENUM-THROAT CALC, P =    0.0
          FRACTION BURNED KEY D =   20.0 MICRONS
          GRAIN DEFLECTION KEY WN    0.0


              PRESSURE          THRUST    FLOW                                        WEB BURNED / LENGTH
TIME     HEAD     EXIT     PLEN                          0.0    8.00  16.00  20.00  24.00  28.00  32.00  36.00  38.00  40.00  LOOP
    PO       PTO     ISP      IMP      SUM W     DEFL


0.02    42.0    19.5    14.0      0.   0.003          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.002     8
   19.5    34.4   115.4      0.    0.000   0.0

0.04   177.8    80.8    14.0      2.   0.014          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.004  0.006     8
   80.8   142.6   167.6      0.    0.000   0.0

0.06   414.1   192.6    14.0      7.   0.041          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.015  0.015     6
  192.6   339.5   179.0      0.    0.001   0.0

0.08   631.5   293.7    14.0     16.   0.086          0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.008  0.030  0.028     2
  293.7   517.8   181.2      0.    0.002   0.0
```

	TAU	G	V	P	A	W	R	RHO
1	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	1.0000E-06	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	3.4918E-02	2.6892E 02	7.1016E 02	1.9833E-02	1.0000E-03	8.4778E-01	1.9496E-04
15	0.0	7.4740E-01	5.8974E 03	6.9189E 02	3.3584E-02	3.6243E-02	8.4431E-01	1.9028E-04
16	3.4017E-03	1.0906E 00	8.9102E 03	6.6680E 02	4.2688E-02	6.7226E-02	8.5504E-01	1.8378E-04
17	1.0157E-02	1.4293E 00	1.2291E 04	6.3122E 02	4.9454E-02	1.0206E-01	8.6521E-01	1.7460E-04
18	2.4894E-02	1.8197E 00	1.7023E 04	5.7623E 02	5.3114E-02	1.3956E-01	8.7557E-01	1.6050E-04
19	1.1650E-01	2.5643E 00	3.9080E 04	3.3139E 02	4.7615E-02	1.7631E-01	8.4385E-01	9.8520E-05

```
                PRESSURE          THRUST   FLOW                                             WEB BURNED / LENGTH
TIME     HEAD      EXIT      PLEN                        0.0    8.00   16.00  20.00  24.00  28.00  32.00  36.00  38.00  40.00  LOOP
      PO        PTO      ISP       IMP     SUM W    DEPL

0.12   710.2   331.4    14.0      32.   0.176         0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.041  0.063  0.061    8
   331.4   583.3   181.4       1.   0.007   0.0

0.16   765.9   353.6    14.0      56.   0.307         0.0    0.0    0.0    0.0    0.0    0.0    0.018  0.076  0.098  0.095   10
   353.6   621.2   183.9       3.   0.017   0.0
16 -9.7428E-02   8.0848E 02   5.5000E-01   1.0000E 00
17  6.3782E-03   8.1271E 02   5.5000E-01   9.9366E-01
18 -9.7992E-02   8.0803E 02   6.0000E-01   1.0000E 00
19  6.2957E-03   8.1257E 02   6.0000E-01   9.9375E-01
20 -9.5931E-02   8.0808E 02   6.0000E-01   1.0000E 00
21  6.4125E-03   8.1271E 02   6.0000E-01   9.9363E-01
22 -9.7345E-02   8.0809E 02   6.0000E-01   1.0000E 00
23  6.9132E-03   8.1309E 02   6.0000E-01   9.9313E-01
24 -1.0264E-01   8.0795E 02   6.0000E-01   1.0000E 00
25  6.4831E-03   8.1263E 02   6.0000E-01   9.9356E-01
26 -9.6486E-02   8.0809E 02   6.0000E-01   1.0000E 00
27  6.6662E-03   8.1291E 02   6.0000E-01   9.9338E-01
28 -1.0026E-01   8.0800E 02   6.0000E-01   1.0000E 00
29  6.5813E-03   8.1276E 02   6.0000E-01   9.9346E-01
30 -9.8267E-02   8.0805E 02   6.0000E-01   1.0000E 00
31  6.6299E-03   8.1284E 02   6.0000E-01   9.9341E-01
32 -9.9804E-02   8.0798E 02   6.0000E-01   1.0000E 00

0.20   808.0   408.6    14.0      89.   0.480         0.0    0.0    0.0    0.0    0.0    0.0    0.053  0.112  0.135  0.131   32
   408.6   649.3   185.7       6.   0.033   0.0

0.24   840.5   367.6    14.0     126.   0.686         0.0    0.0    0.0    0.0    0.0    0.018  0.090  0.149  0.172  0.168    3
   367.6   648.1   183.9      10.   0.056   0.0
19   3.1166E-03

0.28   858.0   368.5    14.0     169.   0.920         0.0    0.0    0.0    0.0    0.0    0.055  0.127  0.187  0.210  0.204    1
   368.5   648.8   184.0      16.   0.088   0.0

0.32   878.4   367.8    14.0     218.   1.186         0.0    0.0    0.0    0.0    0.019  0.093  0.165  0.225  0.247  0.240    1
   367.8   648.4   184.1      24.   0.130   0.0

0.36   894.7   367.0    14.0     273.   1.483         0.0    0.0    0.0    0.0    0.056  0.131  0.203  0.262  0.285  0.277    1
   367.0   647.0   184.1      34.   0.184   0.0

0.40   911.3   366.4    14.0     334.   1.812         0.0    0.0    0.0    0.019  0.095  0.170  0.242  0.300  0.322  0.313    1
   366.4   645.8   184.2      46.   0.249   0.0

0.44   926.5   365.8    14.0     400.   2.174         0.0    0.0    0.0    0.057  0.133  0.208  0.280  0.338  0.359  0.349    1
   365.8   644.9   184.2      61.   0.329   0.0

0.48   941.4   365.6    14.0     473.   2.569         0.0    0.0    0.019  0.096  0.173  0.247  0.318  0.375  0.397  0.385    1
   365.6   644.5   184.3      78.   0.424   0.0

0.56   870.3   336.1    14.0     581.   3.160         0.0    0.0    0.096  0.173  0.250  0.323  0.393  0.449  0.469  0.455    4
   336.1   592.5   183.9     120.   0.653   0.0

0.64   871.1   330.1    14.0     730.   3.973         0.0    0.037  0.172  0.249  0.325  0.397  0.465  0.520  0.540  0.523    1
   330.1   582.0   183.7     173.   0.939   0.0

0.72   897.1   333.8    14.0     919.   5.003         0.0    0.113  0.248  0.325  0.399  0.470  0.537  0.591  0.610  0.590    0
   333.8   588.5   183.7     239.   1.298   0.0


0.80   927.9   340.2    14.0    1143.   6.220         0.039  0.190  0.326  0.401  0.474  0.544  0.610  0.662  0.680  0.659    0
   340.2   599.7   183.8     321.   1.746   0.0

0.90   851.1   327.1    14.0    1371.   7.465         0.133  0.265  0.422  0.496  0.567  0.636  0.699  0.750  0.768  0.743    6
   327.1   576.6   183.6     447.   2.431   0.0

1.00   761.4   305.5    14.0    1550.   8.472         0.223  0.376  0.513  0.586  0.657  0.724  0.786  0.836  0.853  0.825    4
   305.5   538.5   1[illegible].0     593.   3.228   0.0
```

	TAU	G	V	P	A	M	R	RHO
1	0.0	0.0	0.0	6.7708E 02	4.3108E-01	0.0	8.2723E-01	1.8557E-04
2	0.0	5.5476E-01	4.5489E 03	6.6499E 02	6.2365E-01	4.9925E-01	8.2131E-01	1.8302E-04
3	0.0	8.8734E-01	7.4872E 03	6.4508E 02	8.6280E-01	1.1048E 00	8.2654E-01	1.7786E-04
4	3.2376E-03	1.1139E 00	9.7361E 03	6.2151E 02	1.1327E 00	1.8207E 00	8.3072E-01	1.7169E-04
5	6.5243E-03	1.3270E 00	1.2118E 04	5.9325E 02	1.3757E 00	2.6342E 00	8.3352E-01	1.6433E-04
6	7.8359E-03	1.3923E 00	1.3006E 04	5.7935E 02	1.5304E 00	3.0747E 00	8.3178E-01	1.6065E-04
7	9.1333E-03	1.4487E 00	1.3853E 04	5.6531E 02	1.6929E 00	3.5309E 00	8.2924E-01	1.5694E-04
8	1.0478E-02	1.5000E 00	1.4698E 04	5.5100E 02	1.8599E 00	4.0258E 00	8.2617E-01	1.5315E-04
9	1.1891E-02	1.5476E 00	1.5559E 04	5.3634E 02	2.0305E 00	4.5346E 00	8.2262E-01	1.4920E-04
10	1.3394E-02	1.5924E 00	1.6448E 04	5.2125E 02	2.2038E 00	5.0640E 00	8.1861E-01	1.4529E-04
11	1.5022E-02	1.6353E 00	1.7385E 04	5.0562E 02	2.3787E 00	5.6131E 00	8.1417E-01	1.4117E-04
12	1.6822E-02	1.6772E 00	1.8395E 04	4.8924E 02	2.5537E 00	6.1805E 00	8.0924E-01	1.3683E-04
13	1.8891E-02	1.7199E 00	1.9517E 04	4.7181E 02	2.7257E 00	6.7648E 00	8.0387E-01	1.3225E-04
14	2.1354E-02	1.7648E 00	2.0808E 04	4.5288E 02	2.8918E 00	7.3643E 00	7.9796E-01	1.2729E-04
15	2.5361E-02	1.8322E 00	2.2692E 04	4.2932E 02	3.0165E 00	7.9755E 00	7.9225E-01	1.2117E-04
16	2.7766E-02	1.8657E 00	2.3773E 04	4.1618E 02	3.0772E 00	[illegible].7844E 00	7.8865E-01	1.1778E-04
17	3.1155E-02	1.9108E 00	2.5230E 04	4.0007E 02	3.1170E 00	8.5945E 00	7.8492E-01	1.1365E-04
18	3.6245E-02	1.9715E 00	2.7344E 04	3.7868E 02	3.1299E 00	8.[illegible]45E 00	7.8031E-01	1.0820E-04
19	6.4916E-02	2.1807E 00	3.9099E 04	2.8048E 02	2.9248E 00	9.2037E 00	7.5177E-01	8.3458E-05

TIME / PO	PRESSURE HEAD / PTO	PRESSURE EXIT / ISP	PRESSURE PLEN / IMP	THRUST / SUM W	FLOW / DEFL	WEB BURNED / LENGTH 0.0	8.00	16.00	20.00	24.00	28.00	32.00	36.00	38.00	40.00	LOOP
1.10	677.1	280.5	14.0	1678.	9.204	0.308	0.462	0.599	0.672	0.741	0.808	0.869	0.917	0.934	0.902	1
280.5	494.4	182.4	754.	4.111	0.0											
1.20	603.8	255.8	14.0	1766.	9.723	0.388	0.542	0.680	0.752	0.821	0.887	0.947	0.994	1.010	0.975	1
255.8	451.0	181.6	927.	5.058	0.0											
1.30	540.5	235.0	14.0	1828.	10.099	0.465	0.617	0.756	0.828	0.897	0.961	1.021	1.067	1.082	1.044	4
235.0	412.4	181.0	1106.	6.049	0.0											
1.40	488.8	215.3	14.0	1871.	10.380	0.537	0.689	0.828	0.899	0.968	1.032	1.090	1.136	1.150	1.108	7
215.3	378.1	180.3	1291.	7.073	0.0											
1.50	445.5	198.7	14.0	1903.	10.596	0.607	0.757	0.896	0.967	1.035	1.099	1.157	1.201	1.214	1.169	6
198.7	348.7	179.6	1480.	8.122	0.0											
1.60	409.1	184.2	14.0	1926.	10.771	0.673	0.822	0.961	1.032	1.099	1.162	1.219	1.262	1.275	1.226	7
184.2	323.4	178.8	1671.	9.190	0.0											
1.70	378.4	172.0	14.0	1945.	10.919	0.737	0.885	1.023	1.093	1.161	1.223	1.279	1.321	1.333	1.280	7
172.0	301.7	178.2	1865.	10.274	0.0											
1.80	352.3	161.1	14.0	1962.	11.052	0.798	0.946	1.082	1.152	1.219	1.281	1.337	1.378	1.389	1.332	8
161.1	283.0	177.5	2060.	11.373	0.0											
1.90	329.7	152.0	14.0	1976.	11.173	0.858	1.005	1.139	1.209	1.276	1.337	1.392	1.432	1.442	1.381	8
152.0	266.8	176.8	2257.	12.484	0.0											
2.00	310.3	144.0	14.0	1989.	11.288	0.915	1.062	1.194	1.264	1.330	1.391	1.445	1.484	1.494	1.428	8
144.0	252.6	176.2	2456.	13.607	0.0											
2.10	293.3	136.8	14.0	2002.	11.400	0.971	1.117	1.248	1.317	1.383	1.443	1.497	1.535	1.543	1.473	9
136.8	240.2	175.6	2655.	14.742	0.0											
2.20	278.4	130.6	14.0	2015.	11.510	1.026	1.171	1.301	1.369	1.434	1.494	1.546	1.583	1.591	1.517	9
130.6	229.2	175.0	2856.	15.887	0.0											
2.30	265.2	125.1	14.0	2027.	11.619	1.079	1.224	1.352	1.419	1.483	1.543	1.595	1.631	1.638	1.559	9
125.1	219.5	174.5	3058.	17.044	0.0											
2.40	253.5	120.2	14.0	2040.	11.728	1.132	1.275	1.403	1.469	1.532	1.590	1.642	1.676	1.683	1.600	9
120.2	210.8	174.0	3261.	18.211	0.0											
2.50	243.0	115.7	14.0	2053.	11.837	1.183	1.326	1.452	1.517	1.579	1.637	1.687	1.721	1.726	1.639	9
115.7	202.9	173.5	3466.	19.389	0.0											
2.60	233.5	111.5	14.0	2066.	11.946	1.233	1.375	1.500	1.565	1.626	1.682	1.732	1.764	1.769	1.678	10
111.5	195.8	173.0	3672.	20.578	0.0											
2.70	224.9	108.0	14.0	2079.	12.055	1.282	1.424	1.548	1.612	1.672	1.727	1.775	1.807	1.811	1.715	9
108.0	189.4	172.5	3879.	21.778	0.0											
2.80	217.1	104.5	[illegible]	2092.	12.164	1.330	1.472	1.595	1.657	1.717	1.771	1.818	1.848	1.851	1.751	10
104.5	183.5	172.0	4088.	22.989	0.0											
2.90	209.9	101.4	14.0	2106.	12.273	1.378	1.519	1.640	1.703	1.761	1.814	1.860	1.889	1.891	1.786	10
101.4	178.1	[illegible]	4298.	24.211	0.0											

[illegible].00	203.3	98.6	14.0	2119.	12.381	1.424	1.565	1.686	1.747	1.804	1.856	1.901	1.928	1.930	1.821	10
98.6	173.1	171.1	4509.	25.444	0.0											
3.10	197.2	96.0	14.0	2132.	12.487	1.470	1.611	1.730	1.791	1.847	1.898	1.941	1.967	1.968	1.855	10
96.0	168.5	170.7	4722.	26.687	0.0											
3.20	191.5	93.5	14.0	2144.	12.590	1.516	1.656	1.774	1.834	1.890	1.939	1.981	2.005	2.005	1.888	10
93.5	164.1	170.3	4935.	27.941	0.0											
3.30	186.1	91.2	14.0	2156.	12.693	1.560	1.700	1.817	1.876	1.931	1.980	2.021	2.043	2.042	1.920	10
91.2	160.0	169.9	5150.	29.205	0.0											
3.40	181.2	89.0	14.0	2169.	12.796	1.604	1.744	1.860	1.918	1.972	2.020	2.060	2.081	2.078	1.952	10
89.0	156.3	169.5	5[illegible]7.	3[illegible].479	0.0											
3.50	176.6	87.0	14.0	2181.	12.900	1.648	1.787	1.902	1.960	2.013	2.060	2.098	2.118	2.114	1.983	10
87.0	152.7	169.1	5584.	31.764	0.0											
3.60	172.2	85.1	14.0	2194.	13.002	1.690	1.829	1.943	2.001	2.053	2.099	2.136	2.154	2.149	2.014	10
85.1	149.4	168.7	5803.	33.059	0.0											
3.70	168.2	83.4	14.0	2206.	13.103	1.733	1.871	1.[illegible]84	2.041	2.093	2.138	2.174	2.190	2.184	2.044	10
83.4	146.3	168.3	6023.	34.365	0.0											
3.80	164.3	81.7	14.0	2218.	13.201	1.774	1.912	2.025	2.081	2.132	2.176	2.211	2.226	2.219	2.074	10
81.7	143.3	168.0	6244.	35.680	0.0											
3.90	160.6	80.0	14.0	2229.	13.298	1.816	1.953	2.065	2.120	2.171	2.214	2.248	2.261	2.253	2.1[illegible]	10
80.0	140.5	167.6	6466.	37.005	0.0											
4.00	157.2	78.5	14.0	2240.	13.392	1.856	1.994	2.105	2.159	2.209	2.251	2.284	2.296	2.287	2.132	10
78.5	137.8	167.2	6690.	38.339	0.0											
4.10	153.8	77.1	14.0	2251.	13.485	1.897	2.034	2.144	2.198	2.247	2.288	2.320	2.331	2.321	2.160	10
77.1	135.2	166.9	6914.	39.683	0.0											
4.20	150.7	75.6	14.0	2261.	13.576	1.937	2.073	2.183	2.236	2.284	2.325	2.356	2.365	2.354	2.188	10
75.6	132.7	166.5	7140.	41.036	0.0											
4.30	147.6	74.3	14.0	2271.	13.664	1.976	2.113	2.221	2.274	2.321	2.362	2.391	2.399	2.387	2.216	10
74.3	130.3	166.2	7366.	42.398	0.0											
4.40	144.7	73.0	14.0	2280.	13.748	2.015	2.151	2.259	2.311	2.358	2.398	2.426	2.433	2.420	2.244	10
73.0	128.0	165.8	7594.	43.769	0.0											
4.50	115.0	57.7	14.0	1792.	11.147	2.052	2.188	2.294	2.346	2.392	2.431	2.438	2.438	2.438	.2.270	11
57.7	101.3	160.8	7798.	45.013	0.0											

	TAU	G	V	P	A	W	R	RHO
1	0.0	0.0	0.0	8.1762E 01	1.4468E 01	0.0	2.9064E-01	2.4087E-05
2	0.0	5.1037E-02	3.1872E 03	8.1190E 01	1.5419E 01	1.1095E 00	2.8967E-01	2.3931E-05
3	0.0	9.7478E-02	6.2009E 03	7.9588E 01	1.6353E 01	2.2475E 00	2.8692E-01	2.3493E-05
4	0.0	1.4005E-01	9.1793E 03	7.7059E 01	1.7250E 01	3.4060E 00	2.8253E-01	2.[illegible]800E-05
5	0.0	1.8114E-01	1.2402E 04	7.3504E 01	1.7905E 01	4.5726E 00	2.7623E-01	2.[illegible]827E-05
6	0.0	1.9985E-01	1.4062E 04	7.1363E 01	1.8298E 01	5.1559E 00	2.7235E-01	[illegible].1240E-05
7	0.0	2.1787E-01	1.5826E 04	6.8932E 01	1.8681E 01	5.7381F 00	2.6788E-01	2.0573E-05
8	0.0	2.3533E-01	1.7753E 04	6.6153E 01	1.9042E 01	6.3178E 00	2.6266E-01	1.9810E-05
9	0.0	2.5231E-01	1.9921E 04	6.2936E 01	1.9378E 01	6.8934E 00	2.5648E-01	1.8928E-05
10	0.0	2.6938E-01	2.2527E 04	5.9074E 01	1.9635E 01	7.4572E 00	2.4883E-01	1.7871E-05
11	0.0	2.8091E-01	2.4571E 04	5.6189E 01	1.9635E 01	7.7764E 00	2.4295E-01	1.7085E-05
12	0.0	2.8210E-01	2.4798E 04	5.5877E 01	1.9635E 01	7.8093E 00	2.4230E-01	1.7000E-05
13	0.0	2.8222E-01	2.4815E 04	5.5860E 01	1.9635E 01	7.8128E 00	2.4227E-01	1.6996E-05
14	0.0	2.8234E-01	2.4832E 04	5.5844E 01	1.9635E 01	7.8160E 00	2.4224E-01	1.6992E-05
15	0.0	2.8245E-01	2.4848E 04	5.5829E 01	1.9635E 01	7.8191E 00	2.4[illegible]20E-01	1.6988E-05
16	0.0	2.8251E-01	2.4856E 04	5.5821E 01	1.9635E 01	7.8207E 00	2.4219E-01	1.6986E-05
17	0.0	2.8256E-01	2.4863E 04	5.5814E 01	1.9635E 01	7.8222E 00	2.4217E-01	1.6984E-05
18	0.0	2.8290E-01	2.4928E 04	5.5725E 01	1.9635E 01	7.8316E 00	2.4199E-01	1.6960E-05
19	0.0	3.2799E-01	3.7667E 04	4.0919E 01	1.7422E 01	8.0567E 00	2.0885E-01	1.3013E-05

```
               PRESSURE          THRUST    FLOW                               WEB BURNED / LENGTH
TIME     HEAD     EXIT     PLEN                              0.0    8.00  16.00  20.00  24.00  28.00  32.00  36.00  38.00  40.00  LOOP
     P*       PT*     ISP       IMP      SUM W     DEFL


4.60    81.8     40.9     14.0    1216.    8.057            2.084  2.219  2.325  2.376  2.421  2.438  2.438  2.438  2.438  2.292    12
     40.9     71.9    150.9    7948.   45.974    0.0

4.70    61.9     31.0     14.0     969.    6.196            2.111  2.246  2.351  2.401  2.438  2.438  2.438  2.438  2.438  2.312    12
     31.0     54.4    140.3    8052.   46.686    0.0

4.80    49.2     24.7     14.0     646.    4.994            2.135  2.270  2.373  2.422  2.438  2.438  2.438  2.438  2.438  2.328    13
     24.7     43.3    129.3    8128.   47.246    0.0

4.90    40.2     20.2     14.0     484.    4.122            2.157  2.291  2.393  2.438  2.438  2.438  2.438  2.438  2.438  2.339    15
     20.2     35.5    117.5    8185.   47.702    0.0
16 -1.0116E-02  3.2445E 01  1.0245E 00  1.0000E 00
17 -9.2380E-03  3.2443E 01  1.0245E 00  1.0000E 00
18 -8.4393E-03  3.2440E 01  9.7452E-01  1.0000E 00
19 -7.7535E-03  3.2438E 01  9.7452E-01  1.0000E 00
20 -7.1572E-03  3.2437E 01  9.7452E-01  1.0000E 00
21 -6.5607E-03  3.2435E 01  9.7452E-01  1.0000E 00
22 -6.0819E-03  3.2434E 01  9.7452E-01  1.0000E 00
23 -5.7613E-03  3.2433E 01  9.7452E-01  1.0000E 00
24 -5.4426E-03  3.2432E 01  9.7452E-01  1.0000E 00
25 -5.1270E-03  3.2431E 01  9.7452E-01  1.0000E 00

                                       L* WARNING AT 41.20

5.00    32.4     16.4     14.0     343.    3.353            2.176  2.310  2.409  2.438  2.438  2.438  2.438  2.438  2.438  2.347    26
     16.4     28.7    102.3    8226.   48.075    0.0

THROAT UNCHOKED

AVERAGE THRUST AND ISP ARE 1618. LBM, 170.6 SEC        WITH ACTION TIME OF 5.099 SECONDS
    MAXIMUM THRUST IS  2280. LB, AND MAXIMUM PRESSURE IS  941.42 PSIA

5.10    23.3     13.9     14.0     173.    2.348            2.192  2.325  2.419  2.438  2.438  2.438  2.438  2.438  2.438  2.354     9
     13.9     20.6     73.5    8252.   48.360    0.0

STOP ISP = 164.16, BASED ON LOADED WEIGHT OF    50.3 LBS
```

The axial distribution along the port at t = 0.10 shows velocity V increasing to sonic (39,529 in./sec) at node 17. The throat is beyond the minimum area due to mass addition, and area A at node 17 is not the minimum due to burning.

The run proceeds normally with pressure decreasing and the throat moving aft until 3.30 seconds. At this time, a large portion of the web burns out and the L* warning is bypassed. Because burnout was sudden, the motor pressure decays rapidly, the motor unchokes, and action time is sensed prior to the 3.50-second printout. The run is terminated after 3.60 seconds as the pressure falls within 2.0 psi of ambient. The integral of mass flow and the loaded weight do not agree well for this type of sharp decay, and the user may need to reduce time steps during tailoff for more precise integration.

The second case in the sample batch has a cylindrical port and two propellants; the aft propellant is assumed to have half the base burn rate of the forward (and prior case) propellant. Also, the erosive burning correlation is assumed and is input the same as for the first propellant. The axial length of the beginning of the second propellant, Z(6) = 36, "keys" the option and is noted by two printouts of the line "EROSION MODEL....".

Since other changes were not input, the second case is the same as the first except that the cylinder of propellant No. 2 replaces the aft 4 inches of propellant/cone in the first case. The slower-burning aft propellant causes the motor to tail off with 0.586 inch of web remaining and the run terminates at 2.7 seconds due to low pressure.

The third case is a motor with fuse ignition. The input includes revised geometry to set the port ID to fuse diameter (table 3), and a negative value of X2 in Z(6) is input to cancel the two-propellant option from the previous case. The fuse velocity, VFZ in Z(15), "keys" the fuse option and the beginning location of the ignition front is given as node 19 in NUM(9), to designate starting at the aft end of the grain. The time steps for this ignition option are internally calculated so that the flame front moves one node for each step. Because the web burned is printed only at alternate nodes, the flame front moves one print increment for every other time step. After the fuse burns to the head, the time steps are obtained from the tabular input as in normal runs.

The rise time is input as 0.8 second in Z(2) to avoid the L* instability test during the fuse ignition period. (A warning would occur at 0.02 second and the test would be canceled, so the meaningful warning at 5.0 seconds would be missed.) The trial pressure PSTART is input as 14.0 psia in Z(22), and with this option becomes the initial pressure in the port for a degenerate calculation at ignition time.

The printout of parameters along the port preceding the 0.12-second normal output indicates that the flame front has moved six increments along the motor, consistent with the web burned profile for that time.

The calculations do not converge at the 0.20-second point but are oscillating between 808 and 813 psia. The computational stability is particularly unpredictable because a wide range of geometry, erosion model, burn rate slope, grain deflection, or aluminum fraction burned are considered. In this example, the 5-psia uncertainty may be assumed small in the effect on overall performance parameters. The user, however, must observe that results are within requirements. At 5.0 seconds, the calculation is substantially overdamped, so decreasing the loop gain FACTOR in Z(25) will reduce the oscillation at 0.20 second, but will increase the number of iterations later. A desirable solution is to decrease the time step size during tailoff, then decrease FACTOR.

The run is terminated due to the input of TSTOP = 5.0 seconds in Z(2).

(The reverse is blank)

APPENDIX A

SYMBOL LIST AND SOURCE PROGRAM LISTING

A complete list of symbols employed in the FORTRAN program is given in Table A-1. The list is approximately in alphabetical order but parameters are grouped to illustrate similarity of related terms. For example, all of the symbols representing burn rate are grouped under R. Any parameters that are input are identified in the second column of the table.

The source program listings of the main program and subroutines DATA IN, TABIN, and TAB comprise Table A-2. The user may find it convenient to recognize the correspondence between the EQUIVALENCE statements in the main program and Tables IV-3 and IV-4 in Section IV of the User's Manual.

TABLE A-1

SYMBOL LIST

Symbol	Input	Parameter	Units	Description
A		A	in.^{2}	Areas, port, to trap slivers
		AL	in.^{2}	saved A last
		AP	in.^{2}	instantaneous port
		ABAR	in.^{2}	average AP (I) and AP (J)
		AHEAD	in.^{2}	head end of grain
		ADEFL	in.^{2}	deflected port
		APT	in.^{2}	saved throat area, used in pressure guess
		ACT	-	Code word, action time printout logic
α		ALPHA		Factor, Lenoir-Robillard (L-R) eq
	X	ALPHAN	-	Relative thermal diffusivity
Al	X	ALUM	-	Aluminum fraction of propellant
		ANG	-	Divergence angle, thrust calculation
		ATERM	-	Factor in L-R eq, $\alpha G^{.8}/X\delta^{.2}$
		BTERM	-	Factor in L-R eq, $-\beta\rho/G$
β	X	BETA	-	Constant in L-R eq
		BETAR	lb/in.^{3}	$\cdot\rho$
	X	BH	-	First coefficient, L-R eq
a		C	in./sec	Sonic velocity
	X	CHOKE	-	Code word to indicate choking
		COEFF		Factor, shear stress calculation
	X	CONV	-	Convergence ratio
		CONV2	-	2 · CONV, axial increments
		CONV1	-	10 · CONV, choke constraint
		COUNT	-	Counter for table lookup, time of detailed output
		COUNTP	-	time of sensitivity calculations
$C_{p,g}$	X	CPG	kcal/g-mole	Specific heats, gas
$C_{p,p}$ or C_p	X	CPP	kcal/g-mole	products (when f = 1.)
		C1	-	$1 - {}_o (1 - f)$
		C2	-	$1 - \quad - f^2)$
	X	D	in.	Diameters, port inner input
	X	DMAX	in.	grain outer
		DIAM	in.	instantaneous port
	X	DPLEN	in.	plenum
	X	DTH	in.	throat of nozzle
	X	DALUM	microns	aluminum particle
		DR	in./sec	Increments, erosive burning
		DP	psi	pressure
		DU	in./sec	velocity
		DWEB	in.	web burned
		DELL	in.	aft end burning length
		DELP	psi	pressure error
δ_t	X	DELT	sec	time increments
		DELT2	sec	$\delta t/2$
δ_x		DX	in.	length
dx_{nom}		DX	-	L/N
		DXDT	in./sec	$\delta x/\delta t$

TABLE A-1 (Continued)

Symbol	Input	Parameter	Units	Description
		DAP	$in.^2$	Incremental area change, used also in locating throat
		DD	in.	Diameter of burn beyond outer diameter (for sliver logic)
		DDJ	in.	Last station
		DEFL	in.	Deflection, instantaneous
	X	DEFLO	in.	reference input
		DEFLN	in.	transient ratio
		DENOM	-	Term in throat location logic
		DIVR	-	Divergence loss term in thrust calculation
	X	DOME	-	Key to hemispherical head option
		F	-	Error ratios, saved value of inner loop
		ERRM	-	Mach number, outer loop
		ERRML	-	last value ERRM
		ERRN	-	over-choke ratio
		ERRU	-	velocity
ϵ		EPS	-	Solid fraction, with slip
		EPS1	-	$1 - \epsilon$
ϵ_o		EO	-	Solid fraction, without slip ($f = 1$)
		EO1	-	$1 - \epsilon_o$
	X	EPSP	-	Plenum-to-throat expansion term, nozzled motors only
		EXPWNT	-	$e^{-\omega_n t}$
f		F	-	Slip ratio, u_p/u_g
		F1	-	$1 - f$
		F1SQ	-	$1 - f^2$
		FAC	-	Convergence factor, outer loop gain
	X	FACTOR	-	input value
		FAULT	-	Indicator of choke constraint error
F		FG	lb	Thrust, instantaneous
		FGL	lb	save prior value
		FAV	lb	average over action time
		FMAX	lb	maximum
		FAL	-	Factor in aluminum-burned calculation
$\overline{F}$		FR	-	Fraction of aluminum burned
		FILL	lb	Loaded propellant weight
		FIX	-	Term used to guess next head pressure
F_x		-	-	Wall frictional force per unit length
G		G	$lb/sec\text{-}in.^2$	Specific mass flow
γ		-	-	Ratio of specific heats for sonic velocity calculation
γ_p		GAMP	-	Ratio of specific heat terms, products
		GAMT	-	$= Tc - Ts/u^2$ (energy equation)
		GF1	-	$\gamma - 1$
		GF2	-	$\gamma + 1$
		GF3	-	$\gamma/(\gamma - 1)$
		GF5	-	$2/(\gamma + 1)$
		G0	in./sec	Mass/weight conversion
G_0		G02	$lb/in.^2\text{-}sec$	Erosive coefficient
		G02X		G_0^m

TABLE A-1 (Continued)

Symbol	Input	Parameter	Input	Description
		H		Matrix to save parametric results
	X	HIGH	in.	Height of two-dimensional port
		I		Index, axial node number
	X	IGN		Ignition time option key
		IPR		Axial print index
		IS		Index, time step in parametric run
I_{sp}		ISP	sec	Specific impulse
		J		Index, I-1
k		KD	lb/in.^{3}	Spring constant in transient deflection calculation
		L		Index, instantaneous head end
		LOOP		Loop counter, inner loop
		LOOPC		outer loop
		LOOPL		limit, inner loop
		LOOPM		limit, outer loop
L^*		LSTAR	in.	Characteristic length
	X	MOLG		Moles of gas/100 gr
	X	MOLP		Moles of products/100 gr
M_g	X	MWTG		Molecular weight of gas
		MOVE		Code word to trap throat movement
$\dot{m}_e$		-	lb/in.-sec	Mass flow added per unit length
μ		MU	lb/in.-sec	Viscosity of gas
		MU2		$\mu^{0.2}$
	X	N		Number of axial nodes
	X	NXRAY		Index, location of r output in parametric runs
	X	NSTAR		Index, throat location
		NP		Index, propellant number
		NPAR		Index, parameter number in parametric runs
p	X	P	psia	Pressure, local
		PL	psia	last value of p_{head}
		PAMB	psia	ambient
		PLO	psia	last value at head
	X	PPLEN	psia	plenum, only if nozzled
	X	PREF	psia	reference for deflection calculation
	X	PSTART	psia	trial value
		PMAX	psia	maximum at head
		P500	-	p/500
		PT STAR	psia	throat stagnation
		PA	-	term in star fuse geometry
$\dot{p}$		PDOT	psi/sec	Rate of head pressure change
		PNUM	-	Floated NP, propellant number
π		PI	-	3.14159
		PI2	-	$\pi/2$
		PI4	-	$\pi/4$
		PI8	-	$\pi/8$
Pr		PR	-	Prandtl number

TABLE A-1 (Continued)

Symbol	Input	Parameter	Units	Description
r		R	in./sec	Burn rate, instantaneous
		RL	in./sec	saved R
		RREAL	in./sec	trapped for slivers
		RJ	in./sec	last value saved to smooth wall shear stress
		RRI	in./sec	present value to smooth wall shear stress
r_o		RO	in./sec	base burn rate
		RATIO	-	MOLG MOLP
		RHI	in.	Hydraulic radius, ith
		RHJ	in.	jth
ρ	X	RHO	$lb/in.^3$	Density, solid propellant
ρ_g		RHOG	$lb/in.^3$	gas
		RHOL	$lb/in.^3$	gas, saved value
$\bar{\rho}$		RHOBAR	$lb/in.^3$	average of ith and jth
	X	RHOAMB	$lb/in.^3$	initial condition in motor
R_g		RG	in./°F	Gas constant, gas
R_p		RP	in./°F	products
R_u		RU	in./°R	universal
		RT	in.	Product Rp · Tc
		S	in.	Perimeter of port
	X	SALUM	-	Coefficient, aluminum slip correlation
		SAL	-	Term, aluminum slip correlation
f_{Al}		SLIP	-	Aluminum slip ratio
	X	SALOX	-	Coefficient, Al_2O_3 slip correlation
		SOX	-	Term, Al_2O_3 slip correlation
$f_{Al_2O_3}$		SLIPOX	-	Al_2O_3 slip ratio
		STAR	-	Number of points in star point
		STEP	-	Counter in parametric runs - = omit, 0 = base run, + = counter
		SUMF	lb	Running sum, thrust
		SUMW	lb	mass flow
		TAIL	-	Indicator for tailoff logic
		TANN	-	Tan (star)
τ		TAUW	psi	Wall shear stress,
$\bar{\tau}$		TAUBAR	psi	average in Δx increment
T_F	X	TC	°R	Chamber temperature
T		TS	°R	Local static temperature
t		TIME	sec	Time,
	X	TSTOP	sec	completion
	X	TPART	sec	values at parametric points
	X	TLIST	sec	values for detail output
		TIME1	sec	adjusted to avoid rounding
		TEMP		Temporary storage of factor to be used with several statements
u_g or U_g		U	in./sec	Gas velocity, instantaneous
		UTRY	in./sec	for convergence check
		UMAX	in./sec	at T → 0 to trap supersonic flow logic
u_p		-		Particle velocity

TABLE A-1 (Continued)

Symbol	Input	Parameter	Units	Description
		V	$in.^3$	Volume, running sum along axis
		VOL	$in.^3$	of plenum
		VOLL	$in.^3$	saved value
	X	VFZ	in./sec	Velocity of ignition upstream spreading
		W	lb/sec	Mass flow, instantaneous
		WL	lb/sec	saved value
		WADD	lb/sec	added in Δx increment
		WBAR	lb/sec	average in Δx increment
w_{ign}	X	WIGN	lb/sec	igniter or head end dome
		WFZ	lb/sec	fuse igniter
		WNL	lb/sec	saved value, exit
		WEBP	in.	Web burned
		WEBM	in.	Initial or maximum web
	X	WIDE	in.	Initial length of star fins
ω_n	X	WN	rad/sec	Natural frequency, deflection calculation
		WNT	-	$\omega_n \cdot \delta t$
		WNT1	-	$1 - \omega_n \delta t$
		WN2	-	$2/\omega_n$
		WN2T	-	$2/\omega_n + \delta t$
x		X	in.	Length,
		XO	in.	to instantaneous head
	X	X2	in.	to second propellant
		XE	in.	motor
		XHEAD	in.	uninhibited head web burn
	X	XPLEN	in.	plenum
		XL	-	X/L
		X50	-	X/50
		XD	in.	Deflection transient term
		XDO	in.	prior value
		XDOT		Rate of change of XD
a	X	XKG	$in.^3/lb$	Coefficient in erosive correlation
m		XM	-	Exponent in erosive correlation
		XR	in./sec	Temporary value of r
		XTERM1 to 5		Factors of transient deflection calculation equation
		Y	in.	Instantaneous width of star fin port
		ZTH	in.	Width of two-dimensional throat

TABLE A-2

SOURCE LISTING

```
C
C       NOZZLELESS ROCKET MOTOR BALLISTICS / EROSIVE BURNING PROPELLANT
C         DYNAMIC MODEL
C
C       LOCKHEED PROPULSION COMPANY / AIR FORCE ROCKET PROPULSION LAB
C
      REAL  ISP,  KD,  MOLG,  MOLP,  MWTG,  MU,  MU2,  LSTAR
      DIMENSION  LOGIC(25),  NUM(25)
      COMMON  /COM2/Z(125)  /COM5/SYSTEM(125)  /COM1/COM(102)
     1 /COM4/MASTER(3000)
      EQUIVALENCE  (LOGIC,SYSTEM(101)),  (NUM,Z(101))
C
      DIMENSION  X(30),  WEBP(30),  DWEB(30),  R(30),  RL(30),  P(30),
     1 U(30),  A(30),  RHOG(30),  G(30),  D(30),  AP(30),  DMAX(30),
     1 WEBM(30),  TAUW(30),  RHOBAR(30),  W(30),  C(30),  E(30),
     1 RHOL(30),  AL(30),  DEFLO(30),  DEFL(30),  DIAM(30),  H(9,15)
C
      DIMENSION  XKG(2),  BH(2),  GO2(2),  PR(2),  RHO(2),  ALPHA(2),
     1 BETAR(2),  XM(2),  GO2X(2)
C
      EQUIVALENCE  (N,NUM),                     (LIST,NUM(12))
C        N = 10, 19, 28, ONLY
C        NUM(4) = -1 IS A REQUIRED KEY
C     (KODE,NUM(2)),  (KEY,NUM(5)),  (IGN,NUM(6)),  (NSTAR,NUM(7))
C    1 (NXRAY,NUM(8)),  (L,NUM(9)),  (LOOPM,NUM(10))
      EQUIVALENCE  (TSTOP,Z),  (TRISE,Z(2)),  (ALUM,Z(3)),  (BETA,Z(4)),
     1 (MU,Z(5)),               (XE,Z(7)),  (XPLEN,Z(8)),  (DPLEN,Z(9)),
     1 (DTH,ZTH,Z(10)),  (PPLEN ,Z(11)),  (WIDE,Z(12)),  (HIGH,Z(13)),
     1 (STAR,Z(14)),  (VFZ,Z(15)),  (STEP,Z(18)),  (DOME,Z(19))
C     EQUIVALENCE  (EPSP,Z(17)),  (X2,Z(6)),  (CHOKE,Z(21)),
C    1 (FACTOR,Z(25)),  (WFZ,Z(16))
      EQUIVALENCE  (CONV,Z(20)),  (RHOAMB,Z(23)),  (PSTART,Z(22)),
     1 (PAMB,Z(24)),  (KD,Z(26)),  (WN,Z(27)),  (PREF,Z(28)),
     1 (ALPHAN,Z(29)),
     1 (GO2,BH,Z(30)),  (XKG,PR,Z(32)),  (XM,Z(34)),  (RHO,Z(36)),
     1 (DALUM,Z(38)),  (SALOX,Z(39)),  (SALUM,Z(40))
C
      EQUIVALENCE  (IS,Z(50)),  (DELL,Z(51)),  (WL,Z(52)),  (XDO,Z(53)),
     1 (XDOT,Z(54)),  (FILL,Z(55)),  (SUMF,Z(56)),  (FMAX,Z(57)),
     1 (PMAX,Z(58)),  (WNL,Z(59)),  (TIME,Z(60)),  (DEFLN,Z(61)),
     1 (COUNT,Z(62)),  (COUNTP,Z(63)),  (TAIL,Z(64)),  (SUMW,Z(65)),
     1 (ACT,Z(66)),  (FGL,Z(67)),  (XHEAD,Z(68))
C
      GO = 386.09
      PI = 3.141592
      PI2 = PI / 2.
      PI4 = PI / 4.
      PI8 = PI / 8.
      RU = 1545. * 12.
      DO 7  I=1,3000
    7 MASTER(I) = 0
      DO 8  I=1,125
    8 Z(I) = 0.
```

```
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      DO 9  I=1,102
    9 COM(I) = 0.
C
C        READ NEW HEADING AND DATA OR CHANGES TO DATA
C          UPDATE INPUT LOGIC WORDS
C
    1 READ (1,99) I
      IF  (I.LT.1) CALL EXIT
      WRITE (3,99) I
   99 FORMAT (I1,71H
     1                       )
      CALL TABIN
      DO 2  I=1,100
    2 IF  (SYSTEM(I).NE.0.) Z(I) = SYSTEM(I)
      DO 3  I=1,25
    3 IF  (LOGIC(I).NE.0) NUM(I) = LOGIC(I)
      IF  (NUM(5).EQ.0) STEP = -1.
      NXRAY = NUM(8)
      IF  (NXRAY.EQ.0) NXRAY = N - 4
    4 DO 5  I=50,68
    5 Z(I) = 0.
      CALL TAB (COUNTP, 0., TPART, 11)
      TANN = TAN (STAR / (2.* PI))
      NSTAR = NUM(7)
      MOVE = NSTAR
      IF  (NSTAP.EQ.0) NSTAR = N
      LOOPM = MAXO (NUM(10), 10)
      IGN = NUM(6)
      IPR = N / 9
      CONV = AMAX1 (CONV, 1.E-5)
      CONV2 = 2. * CONV
      CONV1 = 10. * CONV
      WFZ = Z(16)
      CHOKE = Z(21)
      IF  (KD.EQ.0.) KD = 1.
      IF  (WN.GT.0.) WN2 = 2. / WN
C
C        SET FOR ROUND OR 2-DIMENSIONAL PLENUM AND THROAT SECTIONS
C
      AP(N+2) = PI4 * DTH**2
      AP(N+1) = PI4 * D PLEN**2
      IF  (HIGH.EQ.0.) GO TO 6
      AP(N+2) = HIGH * ZTH
      AP(N+1) = HIGH * D PLEN
    6 VOLL = AP(N+1) * X PLEN
      VOL = VOLL
      PA = AMAX1 (STAR, 1.)
C
C        PREPARE TERMS FOR TWO PROPELLANTS
C
      MU2 = MU**.2
      COEFF = .0288 * MU2 / GO
      X2 = Z(6)
```

```
      NP = 2
      IF  (X2.GT.0.) GO TO 11
      NP = 1
      X2 = XE + 1.
   11 DO 13  I=1,NP
      IF  (XM(I).EQ.0.) XM(I) = 1.
      GO2X(I) = GO2(I)**XM(I)
      BETAR(I) = - BETA * RHO(I)
      WRITE (3,12) NUM(I+1), I, RHO(I), BH(I), PR(I), XM(I), Z(I+5)
   12 FORMAT (17H EROSION MODEL NO I2, 15H FOR PROPELLANT I2, 10X,
     1 6H RHO = F7.4,5X,4HK1 = F7.4,5X,4HK2 = F7.4,5X,5HEXP = F5.2,
     1 5X,11HTO LENGTH = F5.1,4H IN.)
   13 ALPHA(I) = .0288 * MU2 / PR(I)**.6667 * BH(I) / RHO(I)
C
C        FILL LISTS WITH GEOMETRY AND TRIAL VALUES
C
      I = 1
      NP = 1
      X(1) = 0.
      TEMP = N - 1
      CALL TAB (0., 2., DMAX(1), 3)
      GO TO 15
   14 XL = X(I-1) / XE
      CALL TAB (XL, 0., DX, 4)
      DX = DX * XE / TEMP
      X(I) = X(I-1) + DX
      IF  (X(I).GT.X2) NP = 2
      CALL TAB (X(I),2.,DMAX(I),3)
      FILL = FILL + PI8 * DX * RHO(NP) * (DMAX(I)**2 + DMAX(I-1)**2)
   15 CALL TAB (X(I),1.,D(I),3)
      WEBM(I) = .5 * (DMAX(I) - D(I))
      CALL TAB (X(I), 0., DEFLO(I), 7)
      U(I) = 0.
      E(I) = 0.
      R(I) = 0.
      RL(I) = 0.
      WEBP(I) = 0.
      G(I) = 1.E-6
      W(I) = 0.
      P(I) = 0.
      AP(I) = 0.
      TAUW(I) = 0.
      RHOG(I) = 0.
      I = I+1
      IF  (I.LE.N) GO TO 14
      DIAM(NSTAR) = D(NSTAR)
      PL = P PLEN
      PLO = PPLEN
      P(N+1) = AMAX1 (P PLEN, PAMB)
      AHEAD = PI4 * DMAX(1)**2
      CALL TAB (0., 0., DELT, 5)
      CALL TAB (COUNT, 0., TLIST, 6)
C
```

```
      WRITE (3,10) X(NSTAR), X(N), D(1), D(NSTAR), D(N), DMAX(1),
     1 DMAX(NSTAR), DMAX(N), N
   10 FORMAT (18H0 NOMINAL GEOMETRY/18X,4HHEAD4X,6HTHROAT6X,4HEXIT/
     1 8H0 LENGTH14X,2F10.2/12H  INNER DIAM3F10.2/12H  OUTER DIAM3F10.2/
     1 47H0 DETAILED GRAIN DESIGN INPUT IN TABLE 3 TO USE I3,
     1 33H NODES SPACED AS INPUT IN TABLE 4/1H0)
      WRITE (3,16) NUM(5), NXRAY, IGN, HIGH, WIDE, VFZ, DOME, PPLEN,
     1 DALUM, WN
   16 FORMAT (42H0 CONTROL WORDS IN INPUT (NON-ZERO IS KEY)/
     1 10X, 25H PARAMETRIC VARIATION KEY I4, 5X, 13H XRAY NODE NO I3/
     1 10X, 25H IGNITION INPUT DT OPTION I4,/
     1 10X, 24H 2-DIMENSIONAL GRAIN KEY F7.3, 7H (HIGH)/
     1 10X, 24H N-POINT STAR GRAIN KEY  F7.3, 7H (WIDE)/
     1 10X, 24H FUSE IGNITION CONTROL   F7.1, 7H (RATE)/
     1 10X, 24H HEAD-END DOME DESIGN    F7.1/
     1 10X, 24H PLENUM-THROAT CALC, P = F7.1/
     1 10X, 24H FRACTION BURNED KEY D = F7.1, 8H MICRONS/
     1 10X, 24H GRAIN DEFLECTION KEY WN F7.1)
      WRITE (3,17) (X(I),I=1,N,IPR)
   17 FORMAT (1H115X,8HPRESSURE 8X,6HTHRUST3X,4HFLOW36X,19HWEB BURNED /
     1LENGTH/2X,4HTIME4X,4HHEAD4X,4HEXIT4X,4HPLEN25X,10F7.2,2X,4HLOOP/
     17X,2HP*6X,3HPT*4X,3HISP5X,3HIMP4X,5HSUM W4X,4HDEFL/)
C
C        CALCULATE COEFFICIENTS FOR PARTICLE LAG CURVE FITS
C
      FR = 1.
      SLIP = 1.
      SLIPOX = 1.
      IF  (DALUM.LE.0.) GO TO 18
      X50 = XE / 50.
      FAL = (1. - .0084 * DALUM) * X50**.6633
      SAL = SALUM * X50**.1759 / (DALUM / 100.)**.0842
      SOX = SALOX * X50**.0234
C
C        FILL INITIAL CONDITIONS FOR FUSE CONFIGURATION
C
   18 L = 1
      IF  (VFZ.LE.0.) GO TO 19
      L = NUM(9)
      IF  (L.EQ.N) TIME = - CONV
      DELT = (X(L) - X(L-1)) / VFZ
   19 P(L) = P START
      FIX = 2.
C
C        SET CONSTANTS TO BEGIN AT THE INSTANTANEOUS HEAD END
C
   21 CALL TAB (TIME, 0., WIGN, 2)
      WIGN = AMAX1 (WFZ, WIGN)
      FACTOR = Z(25)
      IF  (TIME.GT.TRISE) FACTOR = FACTOR / FR
      IF  (WN.LE.0.) GO TO 22
      WNT = WN * DELT
      WNT1 = 1. - WNT
```

```
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      EXPWNT = EXP (-WNT)
      WN2T = WN2 + DELT
      XTERM1 = KD * (2. * WN * XDO + XDOT)
      XTERM2 = KD * WNT1 * XDO - PLO * (1. + WNT)
      XTERM4 = DELT - WN2
      XTERM5 = (1. - WEBP(NSTAR) / WEBM(NSTAR)) / PREF
   22 DELT2 = .5 * DELT
      I = L
      J = I
      V = 0.
      NP = 1
      DX = 0.
      PNUM = 1.
      ERRN = 1.
      FAULT = 1.
      TAU BAR = 0.
      ERRML = ERRM
C
C        PREPARE PARTICLE LAG TERMS
C
      IF  (DALUM.LE.0.) GO TO 24
      P500 = P(L) / 500.
      FR = AMIN1 (FAL * P500**.1151, 1.)
      SLIP = AMIN1 (SAL * P500**.2271, 1.)
      SLIPOX = AMIN1 (SOX / P500**.0381, 1.)
C
C        UPDATE THERMOCHEMICAL COEFFICIENTS
C          INPUT TABLES ARE ASSUMED IN TERMS AND UNITS OF ISP PROGRAM
C
   24 CALL TAB (FR, 0., TC, 8)
      TC = 1.8 * TC
      CALL TAB (FR, 0., CPP, 9)
      CALL TAB (FR, 0., CPG, 10)
      CALL TAB (FR, 0., MOLG, 13)
      CALL TAB (FR, 0., MOLP, 14)
      RATIO = MOLG / MOLP
      CALL TAB (FR, 0., MWTG, 15)
      RG = RU / MWTG
      EO1 = MWTG * MOLG / 100.
      EO = 1. - EO1
      F = SLIPOX + (1. - FR) * ALUM / EO * (SLIP - SLIPOX)
      F1 = 1. - F
      F1SQ = 1. - F * F
      GAMP = CPP / (CPP - 1.987 * RATIO)
      EPS = EO / (F * EO1 + EO)
      C1 = 1. - EO * F1
      C2 = 1. - EPS * F1SQ
      EPS1 = 1. - EPS
      RP = EPS1 * RG
      TEMP = CPG + (CPP / RATIO - CPG) / F
      C CONS = TEMP / (TEMP - 1.987) * RP * GO
      GF1 = GAMP - 1.
      GF2 = GAMP + 1.
```

```
      GF3 = GAMP / GF1
      GF5 = 2. / GF2
      C(N+2) = SQRT (C CONS * TC * GF5)
      RT = TC * RP
      GAMT = .5 / (GF3 * GO * RG) * (1. - EO * F1SQ) / EO1
      UMAX = SQRT (TC / GAMT)
      IF  (WN.LE.0.) GO TO 30
      PDOT = (P(L) - PLO) / DELT
      XTERM3 = XTERM2 + XTERM1 * DELT + PDOT * WN2T
      XD = EXPWNT * XTERM3 + PLO + PDOT * XTERM4
      DEFLN = XD * XTERM5
      GO TO 30
C
C        TRIAL VALUES FOR FIRST TRY DOWN THE PORT
C
   25 DDJ = DD
      RJ = RRI
      RHJ = RHI
      DX = X(I) - X(J)
      DXDT = DX / DELT
      IF  (U(I).GT.0.) GO TO 30
      G(I) = G(J)
      P(I) = P(J)
      U(I) = U(J)
      R(I) = R(J)
   30 LOOP = -2
      LOOPL = LOOPM
      IF  (I.GE.NSTAR) LOOPL = 2 * LOOPM
      IF  (X(I).LE.X2) GO TO 32
      NP = 2
      PNUM = 2.
C
C        LOCAL PORT AREA AND BURN PERIMETER CALCULATIONS
C          BRANCH FOR DIFFERENT GEOMETRY ASSUMPTIONS
C
   32 IF  (IGN.GT.0) RL(I) = R(I)
      DWEB(I) = DELT * (R(I) + RL(I))
      DIAMI = D(I) + DWEB(I)
      DD = DIAMI - DMAX(I)
      DIAM(I) = AMIN1 (DIAMI, DMAX(I))
      XO = X(I) - X(L)
      IF  (HIGH.GT.0.) GO TO 33
      IF  (WIDE) 34,34,35
   33 AP(I) = DIAM(I) * HIGH
      S = 2. * (DIAM(I) + HIGH)
      GO TO 36
   34 AP(I) = PI4 * DIAM(I)**2
      S = PI * DIAM(I)
      GO TO 36
   35 Y = .5 * DIAM(I) / TANN
      W2 = WIDE - Y
      S = 2. * W2 + PI2 * DIAM(I)
      AP(I) = DIAM(I) * (PI8 * DIAM(I) + W2 + .5 * Y)
```

```
   36 RHI = AP(I) / S
      ABAR = .5 * (AP(I) + AP(J))
      A(I) = A BAR
      IF  (TIME.EQ.0.) GO TO 80
C
C        PROPELLANT BURN RATE SECTION
C          EROSIVE BURN RATE CODE FROM NUM(2) OR NUM(3)
C
      CALL TAB (P(I),PNUM,RO,1)
      IF  (NUM(NP+1) - 2) 41,42,43
   41 DR = (G(I)**XM(NP) - GO2X(NP)) * SQRT (U(I) / C(N+2))
      GO TO 44
   42 DR = G(I) - GO2(NP)
   44 R(I) = RO + XKG(NP) * AMAX1 (DR, 0.)
      GO TO 50
   43 IF  (I.EQ.L) GO TO 49
      A TERM = ALPHA(NP) * G(I)**.8 / XO**.2
      B TERM = - BETA * RHO(NP) / G(I)
      R(I) = AMAX1 (R(I), RO)
   46 XR = RO + A TERM * EXP (B TERM / R(I))
      ERR = ABS (1. - XR / R(I))
      R(I) = XR
      IF  (ERR - CONV) 50,50,46
C
C        PERFORM SUMMATIONS AT EACH AXIAL NODE
C          EXECUTE TRAPS TO SMOOTH THE SLIVERING-OFF TRANSIENTS
C
   49 R(I) = RO
   50 R REAL = R(I)
      IF  (DD.GT.0.0) R REAL = .25 * AMAX1 (DIAM(I) - D(I), 0.) / DELT2
      TS = TC - GAMT * U(I)**2
      IF  (I.GT.NSTAR) GO TO 51
      RHOG(I) = P(I) / (RP * TS)
      GO TO 52
   51 RHOG(I) = G(I) / U(I) / EPS1
   52 C(I) = SQRT (C CONS * TS)
      U TRY = U(I)
      IF  (I.EQ.L) GO TO 57
      DAP = AP(I) - AP(J)
      IF  (DD.LT.0.) GO TO 54
      IF  (DDJ.GT.0.) GO TO 56
      TEMP = DD / (DD - DDJ)
      GO TO 55
   54 IF  (DDJ.LT.0.) GO TO 56
      TEMP = DDJ / (DD - DDJ)
   55 A(I) = A(I) + .5 * DAP * TEMP
   56 W ADD = RHO(NP) * (A(I) - AL(I)) * DXDT
      W(I) = W(J) + W ADD
      RHOBAR(I) = .5 * (RHOG(I) + RHOG(J))
      IF  (IGN.LE.0) W(I) = W(I) - (RHOBAR(I)-RHOL(I)) * ABAR * DXDT
      IF  (W(I).GT.0.) GO TO 58
      P(L) = .75 * P(L)
      GO TO 22
```

```
C
C         TRAP TO AVOID CROSSING MACH = 1
C           COMPLETE CALCULATIONS AT THE NODE
C
   57 IF  (DOME.LT.0.) WIGN = RHO(NP) * R REAL * PI2 * DIAM(I)**2 + WIGN
      RRI = R REAL
      W(L) = WIGN
      CALL TAB (TIME, 0., HEADW, 16)
      IF  (HEADW.EQ.0.) GO TO 58
      W(L) = W(L) + RHO(NP) * RREAL * (AHEAD - AP(L)) * HEADW
      X(L) = XHEAD + (R(L) + RL(L)) * HEADW * DELT2
   58 DEFL(I) = DEFLN * DEFLO(I)
      ADEFL = AP(I) * (1. + 4. * DEFL(I) / DIAM(I))
      G(I) = W(I) / ADEFL * E01
      TAUW(I) = 0.
      IF  (I.GT.NSTAR) GO TO 59
      UC = G(I) / RHOG(I) / EPS1
      U(I) = AMIN1 (C(I), UC)
      IF  (I.EQ.L) GO TO 62
   59 U BAR = .5 * (U(I) + U(J))
      ERRN = U(I) / UC
      RRI = (2. * RJ + R REAL) / 3.
      IF  (G(I).LT.1.) GO TO 61
      TEMP = U(I) * EXP(BETAR(NP) * RRI / G(I))
      TAUW(I) = COEFF / XO * (G(I) * XO)**.8 * TEMP
      TAU BAR = (TAUW(I) + TAUW(J)) / (RHI + RHJ) * DX
   61 DU = U(I) - U(J)
      DP = UBAR / GO * (RHOBAR(I) * DU * C2 + WADD * C1 / ABAR) + TAUBAR
      P(I) = AMAX1 (P(J) - DP, .7 * P(I))
      IF  (I.LE.NSTAR) GO TO 62
      DELP = P(I) - RHOG(I) * RP * TS
      UC = U(I) + GO / G(NSTAR) * DELP
      UC = AMIN1 (U(I) + .25 * (UMAX - U(I)), UC)
      U(I) = AMAX1 (C(NSTAR), UC)
      ERRN = UC / U(I)
C
C         CHECK CONVERGENCE AT EACH AXIAL STATION
C
   62 LOOP = LOOP + 1
      IF  (LOOP.LT.0) GO TO 32
      E(I) = 0.
      IF  (I.EQ.L) GO TO 68
      IF  (U(I).LE.0.) GO TO 68
      ERR U = U(I)/U TRY - 1.
      IF  (ABS(ERR U).LT.CONV2) GO TO 63
      IF  (LOOP.LT.LOOPL) GO TO 32
      E(I) = ERRU
C
C         VERIFY THAT THE THROAT HAS NOT MOVED INTO A DIFFERENT STATION
C
   63 FAULT = FAULT * ERRN
      IF  (I.GT.NSTAR) GO TO 64
      V = V + ABAR * DX
```

```
      IF  (CHOKE.LT.0.) GO TO 68
      IF  (J.LE.MOVE) GO TO 67
      DENOM = WADD / W(I) * GF2 + 4. * TAUBAR / (P(I) + P(J))
      IF  (DAP / A BAR - DENOM.LE.0.) GO TO 67
      NSTAR = J
      I = J
      WRITE (3,66) NSTAR, X(I), DAP
   66 FORMAT (25H0 THROAT LOCATION AT NODE I3, 10H AT LENGTH F5.1,
     1 13H IN,  SLOPE = F6.2/)
      GO TO 69
C
   64 IF  (FAULT.LT.1.) GO TO 65
      IF  (I.LT.N) GO TO 68
      GO TO 83
   65 MOVE = NSTAR
      NSTAR = N
      LOOPC = 0
      GO TO 22
C
   67 IF  (I.EQ.NSTAR) GO TO 74
   68 I = I + 1
   69 J = I - 1
      IF  (I.LE.N) GO TO 25
C
C          DETERMINE PLENUM CONDITIONS (IF ANY)
C             CALCULATE CONVERGENCE FACTORS FOR CHOKED EXIT TO GRAIN
C
      IF  (L.EQ.N) GO TO 81
      IF  (P PLEN) 74,74,70
   70 CALL TAB (P(N+1), P NUM, R(N+1), 3)
      DELL = DELT * R(N+1)
      VOL = VOLL + AP(N+1) * DELL
      EPSP = GF5**(1. / GF1)
      IF  (Z(17).GT.0.) EPSP = Z(17)
      TERM = DELT2 * C(N+2) * A(N+2) * EPSP / VOL
      W(N+1) = W(N) * PA + RHO(NP) * R(N+1) * (AP(N+1) - PA * AP(N))
      W BAR = .5 * (W(N+1) + WL)
      IF  (TERM.GT.0.9) GO TO 72
      P(N+1) = (PL * (1. - TERM) + DELT * RT / VOL * WBAR) / (1. + TERM)
      GO TO 74
   72 P(N+1) = WBAR * RT / (EPSP * AP(N+2) * C(N+2))
   74 IF  (FAULT - 1.) 75,76,81
   75 ERR M = 1./FAULT - 1.
      FAC = 3. * FACTOR * AMIN1 (SQRT (ERRM / .003), .5 * FAULT)
      GO TO 78
   76 ERRM = P(N+1) / P(NSTAR) - 1.
      IF  (CHOKE.LT.0.) GO TO 77
      IF  (ERRM.LE.0.) GO TO 73
      CHOKE = -1.
      NSTAR = N
      WRITE (3,82)
   82 FORMAT (17H0 THROAT UNCHOKED /)
      GO TO 77
```

```
   73 ERRM = U(I) / C(I) - 1.
      FAC = AMIN1 (-FACTOR * ERRM, .8)
      GO TO 78
   77 FAC = FACTOR * ABS(1.01 - U(N) / C(N))
   78 DELP = AMAX1 (-.5, ERRM * FAC)
      P(L) = P(L) * (1. + DELP)
      LOOPC = LOOPC + 1
      IF  (LOOPC.LT.0) GO TO 22
      IF  (ABS(ERRM).LT.CONV1) GO TO 79
      IF  (LOOPC.LT.LOOPM) GO TO 22
      WRITE (3,100) LOOPC, ERRM, P(L), FACTOR, FAULT
  100 FORMAT (I4, 1P6E12.4)
      IF  (LOOPC.EQ.LOOPM+1) FACTOR = FACTOR - SIGN (.05, ERRM * ERRML)
      IF  (LOOPC.LT.2 * LOOPM) GO TO 22
      IF  (ABS(DELP).LT.CONV) GO TO 79
      IF  (ABS(DELP).GT..05) GO TO 1
   79 IF  (I.GE.N) GO TO 81
      FAULT = 1.
      GO TO 68
   80 RHO BAR(I) = RHO AMB
      FILL = FILL - ABAR * DX * RHO(NP)
      GO TO 79
C
C        CHECK FOR CHOKING AT END OF GRAIN
C
   81 IF  (CHOKE.GT.0.) GO TO 83
      V = V + VOL
      IF  (FAULT.EQ.1.) GO TO 83
      CHOKE = 1.
      GO TO 65
C
C        NORMAL OUTPUT AND ADVANCE TIME INCREMENTS
C
   83 TIME1 = TIME + 1.E-4
      IF  (TIME1.LT.TLIST) GO TO 85
      COUNT = COUNT + 1.
      CALL TAB (COUNT, 0., TLIST, 6)
      WRITE (3,84)  (I, TAUW(I), G(I), U(I), P(I), AP(I), W(I), R(I),
     1 RHOG(I), I=1,N)
   84 FORMAT (1H015X,3HTAU9X,1HG11X,1HV11X,1HP11X,1HA11X,1HW11X,1HR11X,
     1 3HRHO/ (I10,1P8E12.4))
      WRITE (3,17) (X(I),I=1,N,IPR)
C
   85 DO 86 I = L,N
      IF  (E(I).NE.0.) WRITE (3,100) I, E(I)
      RL(I) = R(I)
      AL(I) = A(I)
      D(I) = D(I) + DWEB(I)
      RHOL(I) = RHOBAR(I)
   86 WEBP(I) = AMIN1 (WEBP(I) + .5 * DWEB(I), WEBM(I))
      IF  (TIME.LE.0.) GO TO 94
      IGN = 0
C
```

```
C        THRUST CALCULATION
C          OUTPUT SECTION
C
      DIVR = 1.
      ANG = .5 * (DIAM(N) - DIAM(NSTAR))
      IF  (ANG.LE.0.) GO TO 120
      TEMP = X(N) - X(NSTAR)
      DIVR = .5 * (1. + TEMP / SQRT (ANG**2 + TEMP**2))
  120 FG = W(N) * U(N) / GO * DIVR * C1 + ADEFL * (P(N) - PAMB)
      FMAX = AMAX1 (FG, FMAX)
      PMAX = AMAX1 (P(L), PMAX)
C
C        SUMMARY TERMS AND ACTION TIME
C
      ISP = FG / W(N)
      SUMF = SUMF + DELT2 * (FG + FGL)
      SUMW = SUMW + DELT2 * (W(N) + WNL)
      PTSTAR = P(NSTAR) * (1. + .5 * GF1 * (U(NSTAR)/C(NSTAR))**2)**GF3
      IF  (ACT.GT.0.) GO TO 125
      IF  (FG.GT.0.1 * FMAX) GO TO 125
      FAV = SUMF / TIME
      TEMP = SUMF / SUMW
      WRITE (3,123) FAV, TEMP, TIME, FMAX, PMAX
  123 FORMAT (28H0 AVERAGE THRUST AND ISP ARE F6.0,5H LBM, F6.1, 4H SEC
     1 7X, 20H WITH ACTION TIME OF F6.3, 8H SECONDS/ 5X,19H MAXIMUM THRU
     1ST IS F6.0, 28H LB, AND MAXIMUM PRESSURE IS F8.2,5H PSIA/)
      ACT = 1.
C
C        PRINT L* WARNING - CANCEL DURING TAILOFF
C
  125 IF  (TAIL.LT.0.) GO TO 130
      IF  (TIME.LT.TRISE) GO TO 130
      IF  (WEBP(L).LT.WEBM(L)) GO TO 128
      WRITE (3,127)
  127 FORMAT (38H0 L* WARNING SUPPRESSED DURING TAILOFF /)
      GO TO 129
  128 LSTAR = V / AP(NSTAR)
      IF (LSTAR.GT.10.9143*(ALPHAN/R(L)**2)**.4198) GO TO 130
      WRITE (3,105) LSTAR
  105 FORMAT (1H0/46X,13HL* WARNING AT F6.2/)
  129 TAIL = -1.
  130 WRITE (3,104) TIME, P(L), P(N), P(N+1), FG, W(N),
     1 (WEBP(I), I=1,N,IPR), LOOPC, P(NSTAR), PTSTAR, ISP, SUMF, SUMW,
     1 DEFL(NSTAR)
  104 FORMAT (1H0F5.2,3F8.1,F8.0,F8.3,9X,10F7.3,I6/2X,3F8.1,F8.0,2F8.3)
      IF  (LIST.NE.0) WRITE (3,100) LIST, TIME, FG, ADEFL, P(L)
C
C        RETAIN NOMINAL-CASE PARAMETERS
C          CALCULATE SLOPE MATRIX TERMS
C
      IF  (STEP.LT.0.) GO TO 90
      IF  (TIME1.LT.TPART) GO TO 90
      IS = IS + 1
```

```
      IF  (STEP.GT.0.) GO TO 88
      COUNTP = COUNTP + 1.
      CALL TAB (COUNTP, 0., TPART, 11)
      H(1,IS) = TIME
      H(1,IS+1) = 1.E6
      H(2,IS) = P(L)
      H(3,IS) = FG
      H(4,IS) = R(N)
      H(5,IS) = R(NXRAY)
      GO TO 90
C
   88 TPART = H(1,IS+1)
      H(6,IS) = P(L) / H(2,IS) - 1.
      H(7,IS) = FG / H(3,IS) - 1.
      H(8,IS) = R(N) / H(4,IS) - 1.
      H(9,IS) = R(NXRAY) / H(5,IS) - 1.
C
   90 IF  (TIME1.GT.TSTOP) GO TO 109
      IF  (P(L).LT.PAMB+2.) GO TO 109
      FGL = FG
      WNL = W(N)
      WL = W(N+1)
      VOLL = VOL
      PL = P(N+1)
      X(N) = X(N) - DELL
      IF  (WN.LE.0.) GO TO 91
      XDOT = (EXPWNT * (XTERM1 - WN * (XTERM3 + PLO - XDO) + PDOT)
     1          +PDOT) / KD
      XDO = XD / KD
      PLO = P(L)
   91 IF  (L.GT.1) GO TO 95
      XHEAD = X(L)
      IF  (TIME.GT.TRISE) DP = APT / AP(NSTAR)
      IF  (TIME.LE.TRISE) DP = (FIX+1.) / FIX
      DO 93  I=L,NSTAR
   93 P(I) = P(I) * DP
   94 IF  (L.GT.1) GO TO 95
      CALL TAB (TIME, 0., DELT, 5)
      WFZ = 0.
      GO TO 96
   95 L = L - 1
      P(L) = P(L+1) * (FIX + 1.) / FIX
      DELT = (X(L+1) - X(L)) / VFZ
   96 LOOPC = -2
      FIX = FIX + 1.
      APT = AP(NSTAR)
      TIME = TIME + DELT
      GO TO 21
C
C          OUTPUT AND ADVANCE OF PARAMETRIC STUDIES
C
  109 TEMP = SUMF / FILL
      WRITE (3,108) TEMP, FILL
```

```
108 FORMAT (12H0 STOP ISP = F7.2,28H, BASED ON LOADED WEIGHT OF F7.1,
   1 4H LBS / )
    IF  (STEP) 1,110,111
110 WRITE (3,106) (H(1,I), H(2,I), H(3,I), H(4,I), H(5,I), I=1,IS)
106 FORMAT (19H1NOMINAL PARAMETERS / 1H04X, 4HTIME 8X, 6HP HEAD 6X,
   1 2HFG 10X, 2HR* 9X, 5HR(N4) / (5F12.3))
    GO TO 112
111 Z(NPAR) = Z(NPAR) / 1.1
    WRITE (3,107) NPAR, (H(1,I), H(6,I), H(7,I), H(8,I), H(9,I),
   1 I=1,IS)
107 FORMAT (39H1SENSITIVITY DERIVATIVES FOR PARAMETER I3 / 1H04X,
   1 4HTIME 8X, 6HP HEAD 6X, 2HFG 10X, 2HR* 9X, 5HR(N4) / (5F12.3))
112 STEP = STEP + 1.
    CALL TAB (STEP, 0., TEMP, 12)
    N PAR = TEMP + 1.E-6
    IF  (NPAR.EQ.0) GO TO 1
    Z(NPAR) = 1.1 * Z(NPAR)
    GO TO 4
    END
```

```
      SUBROUTINE TAB IN
C
C        INPUT LOGIC FOR VARIOUS TABULAR DATA
C
      DIMENSION  GEOMET(3000), MLIST(102), LOGIC(25)
      COMMON  /COM1/COM(102)  /COM4/MASTER(3000)  /COM5/SYSTEM(125)
      EQUIVALENCE  (GEOMET,MASTER),  (MLIST,COM),  (LOGIC,SYSTEM(101)),
     1 (J,MLIST(101)),  (M,MLIST(102))
C
C
      J = MAXO (J, 1)
    2 ML = J
      CALL DATA IN (0)
      ITYPE = LOGIC(4)
      IF  (ITYPE.LT.0) RETURN
      M = M + 1
      MLIST (M) = ML
      IF  (M.LE.50) GO TO 1
      WRITE (3,12)
   12 FORMAT (1H010X,35H LIMIT OF 50 TABLE INPUTS EXCEEDED /)
      CALL EXIT
    1 MX = LOGIC(1)
      MLIST (MX+50) = M
      NX = MAXO (LOGIC(6), 1)
      NY = MAXO (LOGIC(5), 1)
      N LOG = LOGIC(3)
      MASTER(ML+3) = ITYPE
      MASTER(ML+13) = NY
      MASTER(ML+2) = N LOG
C
C        READ -Y- ARGUMENTS (LIMIT TO 19)
C          MAKE ALTERATIONS FOR NON-RECTANGULAR TABLES
C
      J = ML + 14
      INY = 1
      JUMP = 0
      IF  (ITYPE) 4,4,3
    3 INY = NY
      JUMP = 1
    4 DO 5  I=1,INY
      MASTER(J) = MAXO (LOGIC(I+5), 1)
    5 J = J + 1
      MASTER(ML+7) = J
      DO 7  I=1,NY
      GEOMET(J) = SYSTEM(I)
      IF  (N LOG.GT.0) GEOMET(J) = ALOG (GEOMET(J))
    7 J = J + 1
      INDX = J
      MASTER(ML+6) = INDX
      GEOMET(ML+11) = SYSTEM(1)
C
C        READ -X- ARGUMENTS (LIMIT TO 50)
C
```

```
      J1 = ML + 14
      DO 8  K=1,INY
      IF   (NY.GT.1) CALL DATA IN (1)
      NX = MASTER(J1)
      DO 6  I=1,NX
      IF  (N LOG.GT.0) SYSTEM(I) = ALOG (SYSTEM(I))
      GEOMET(J) = SYSTEM(I)
    6 J = J + 1
    8 J1 = J1 + JUMP
      GEOMET(ML+10) = GEOMET(INDX)
C
C         READ TABLE VALUES -Z-
C
      INDZ = J
      MASTER(ML+8) = INDZ
      J1 = ML + 14
      DO 10  K=1,NY
      CALL DATA IN (1)
      NX = MASTER(J1)
      DO 9  I=1,NX
      IF  (N LOG.GT.0) SYSTEM(I) = ALOG (SYSTEM(I))
      GEOMET(J) = SYSTEM(I)
    9 J = J + 1
   10 J1 = J1 + JUMP
      GEOMET(ML+12) = GEOMET(INDZ)
      GO TO 2
      END
```

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```
      SUBROUTINE TAB (X1, Y1, Z1, MX)
C
C        TABLE LOOK-UP ROUTINE FOR LINEAR INTERPOLATION OF
C          ONE-DIMENSIONAL Z=F(X), OR Z=F(Y), TWO DIMENSIONAL Z=F(X,Y),
C          AND TWO-DIMENSIONAL NON-RECTANGULAR TABLES WITH COLUMNS OF
C          VARYING NUMBERS OF ROWS
C        PERFORM LOG-LOG INTERPOLATION IF CODED (MASTER(3) OR -(ML+2))
C
      DIMENSION  GEOMET(3000), MLIST(102), A(2), JUNK(32)
      COMMON  /COM1/COM(102)  /COM4/MASTER(3000)  /COM5/SYSTEM(125)
      EQUIVALENCE  (GEOMET,MASTER),  (MLIST,COM),  (JUNK,SYSTEM(90))
      EQUIVALENCE  (ITYPE,JUNK(4)),  (JX1,JUNK(5)),  (JY1,JUNK(6)),
     1 (INDX,JUNK(7)),  (INDY,JUNK(8)),  (INDZ,JUNK(9)),
     2 (XS,JUNK(11)),  (YS,JUNK(12)),  (ZS,JUNK(13)),
     3 (NY,JUNK(14)),  (NX1,JUNK(15))
C
      M = MLIST (MX+50)
      IF  (M) 9,7,10
C
C          CODE TO ALLOW ONLY ONE ERROR MESSAGE
C
    7 WRITE (3,8) MX, M
    8 FORMAT (40HO REFERENCE TO UNCORRELATED TABLE NUMBER  2I4 / )
      MLIST (MX+50) = -1
    9 Z1 = 0.
      RETURN
C
   10 X = X1
      Y = Y1
      ML = MLIST(M)
      IF  (MASTER(ML+2).EQ.0) GO TO 25
      X = ALOG (X)
      Y = ALOG (Y)
C
C          MOVE INDICES FROM PREVIOUS ENTRY TO WORKING STORAGE -JUNK-
C
   25 LOW = 0
      J = ML
      DELY = 0.
      DO 27  I=1,30
      JUNK(I) = MASTER(J)
   27 J = J + 1
      NX = NX1
C
C        DETERMINE COLUMN AND Y INTERPOLATION RATIO -DEL Y-
C          SHORT CIRCUIT IF INPUT ARGUMENTS ARE UNCHANGED FROM PRIOR SET
C
      IF  (ABS(XS - X) + ABS(YS - Y)) 67,67,31
   31 DY1 = Y - GEOMET(INDY)
      IF  (DY1) 38,50,33
   32 DY1 = DY2
   33 IF  (JY1 + 1 - NY) 34,50,50
   34 DY2 = Y - GEOMET(INDY+1)
```

```
      IF  (DY2) 40,35,35
C
C          SEQUENCE FORWARD ONE COLUMN
C
   35 INDY = INDY + 1
      IF  (ITYPE) 37,37,36
   36 NX = JUNK(JY1+15)
      INDX = INDX + NX
   37 INDZ = INDZ + NX
      JY1 = JY1 + 1
      IF  (LOW) 32,32,50
C
C          SEQUENCE BACKWARDS ONE COLUMN
   38 IF  (JY1) 50,50,39
   39 INDY = INDY - 1
      JY1 = JY1 - 1
      IF  (ITYPE) 42,42,41
   41 NX = JUNK(JY1+15)
      INDX = INDX - NX
   42 INDZ = INDZ - NX
      DY2 = DY1
      DY1 = Y - GEOMET(INDY)
      IF  (DY1) 38,50,40
   40 DELY = DY1 / (DY1 - DY2)
C
C          CONTINUE TO FIND X INTERPOLATION RATIO AND Z VALUE (ONE OR
C            TWO VALUES AS REQUIRED)
C
   50 DELX = 0.
C          COUNT BACK TO THE END OF THE COLUMN (NON-RECTANGULAR)
      IF  (ITYPE) 51,51,48
   48 NX = JUNK(JY1+15)
      I = JX1 + 1 - NX
      IF  (I) 51,51,49
   49 JX1 = JX1 - I
      INDX = INDX - I
      INDZ = INDZ - I
C
   51 DX1 = X - GEOMET(INDX)
      IF  (DX1) 55,58,52
   52 IF  (JX1 + 1 - NX) 53,58,58
   53 DX2 = X - GEOMET(INDX+1)
      IF  (DX2) 57,54,54
C          COUNT FORWARD ONE ROW
   54 JX1 = JX1 + 1
      INDX = INDX + 1
      INDZ = INDZ + 1
      DX1 = DX2
      GO TO 52
   55 IF  (JX1) 58,58,56
C          COUNT BACKWARDS ONE ROW
   56 JX1 = JX1 - 1
      INDX = INDX - 1
```

```
      INDZ = INDZ - 1
      DX2 = DX1
      DX1 = X - GEOMET(INDX)
      IF  (DX1) 55,58,57
C
   57 DELX = DX1 / (DX1 - DX2)
      A(LOW+1) = GEOMET(INDZ) + DELX * (GEOMET(INDZ+1) - GEOMET(INDZ))
      GO TO 60
   58 A(LOW+1) = GEOMET(INDZ)
C
C         RESTORE STORED INDICES AND SET-UP SECOND X INTERPOLATION
C           SECOND X VALUE AND A Y INTERPOLATION IS NEEDED ONLY IF
C           -DELY- HAS BEEN SET POSITIVE
C
   60 IF  (LOW) 61,61,65
   61 LOW = 1
      J = ML + 4
      DO 62  I=5,9
      MASTER(J) = JUNK(I)
   62 J = J + 1
      IF  (DELY) 63,63,35
   63 GEOMET(ML+12) = A(1)
      GO TO 66
C
C         COMPLETE TWO-DIMENSIONAL INTERPOLATION
C         SAVE VALUES X, Y, AND Z FOR SHORT CIRCUIT ON RE-ENTRY
C
   65 GEOMET(ML+12) = A(1) + DELY * (A(2) - A(1))
   66 GEOMET(ML+10) = X
      GEOMET(ML+11) = Y
   67 ANS = GEOMET(ML+12)
      Z1 = ANS
      IF  (MASTER(ML+2). NE.0) Z1 = EXP (ANS)
      RETURN
      END
```

[redacted]

```
      SUBROUTINE DATA IN (N)
C
C        READ RANDOM-ENTRY DATA TO ESTABLISH PROBLEM DEFINITION
C
C          STACK EACH GROUP WITH INTEGERS FIRST, THEN FLOATING DATA
C          CONTROL KEY -N- CALLS FOR DATA ONLY IF (+), BOTH IF (0), OR
C          INTEGERS ONLY IF (-)
C
C        READ UP TO 6 PAIRS (LOCATION I2, DATA (I4,6X) OR F10) PER CARD
C          ANY FIELD MAY BE BLANK --- NUMBER FIRST LOCATION IN LISTS
C          (-) LOCATION OR BLANK CARD TERMINATES SEQUENCE
C
      DIMENSION  L(7), K(6), E(6), LOGIC(25), COMENT(7)
      COMMON  /COM5/SYSTEM(125)
      EQUIVALENCE  (LOGIC,SYSTEM(101))
C
      IF  (N) 1,1,11
    1 DO 2  I=1,25
    2 LOGIC(I) = 0
   22 READ (1,3) (L(I),K(I),I=1,4), L(5), (COMENT(I),I=1,7)
    3 FORMAT (4(I2,I4, 6X), I2, 7A4)
      WRITE (3,23) (COMENT(I),I=1,7)
   23 FORMAT (/6H LOGIC 10X, 7A4)
      J = 0
      K1 = 1
      DO 9  I=1,4
      IF  (L(I)) 5,6,5
    5 J = L(I)
      IF  (J) 10,8,8
    6 IF  (J) 7,9,7
    7 J = J + 1
      IF  (K(I)) 8,9,8
    8 LOGIC(J) = K(I)
      K1 = I
    9 CONTINUE
   10 WRITE (3,4) (L(I),K(I),I=1,K1), L(K1+1)
    4 FORMAT (6X,6(I8,I5,7X))
      IF  (J) 30,30,29
   29 IF  (L(5)) 30,22,22
   30 IF  (N) 21,11,11
C
   11 DO 12  I=1,50
   12 SYSTEM(I) = 0.
   32 READ (1,13) (L(I),E(I),I=1,6), L(7)
   13 FORMAT (6(I2,F10.5), I2)
      J = 0
      K1 = 1
      DO 19  I=1,6
      IF  (L(I)) 15,16,15
   15 J = L(I)
      IF  (J) 20,18,18
   16 IF  (J) 17,19,17
   17 J = J + 1
      IF  (E(I)) 18,19,18
   18 SYSTEM(J) = E(I)
      K1 = I
   19 CONTINUE
   20 WRITE (3,14) (L(I),E(I),I=1,K1), L(K1+1)
   14 FORMAT (6H  DATA 6(I8,F12.6), I4)
      IF  (J) 21,21,24
   24 IF  (L(7)) 21,32,32
C
   21 RETURN
      END
```